

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
13 April 2006 (13.04.2006)

PCT

(10) International Publication Number
WO 2006/039713 A2(51) International Patent Classification:
G06F 15/78 (2006.01)(21) International Application Number:
PCT/US2005/035818

(22) International Filing Date: 3 October 2005 (03.10.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/615,192	1 October 2004 (01.10.2004)	US
60/615,193	1 October 2004 (01.10.2004)	US
60/615,050	1 October 2004 (01.10.2004)	US
60/615,158	1 October 2004 (01.10.2004)	US

(63) Related by continuation (CON) or continuation-in-part (CIP) to earlier applications:

US	60/615,192 (CIP)
Filed on	Not furnished
US	60/615,157 (CIP)
Filed on	Not furnished
US	60/615,170 (CIP)
Filed on	Not furnished
US	60/615,158 (CIP)
Filed on	Not furnished
US	60/615,193 (CIP)
Filed on	Not furnished
US	60/615,050 (CIP)
Filed on	Not furnished

(71) Applicant (for all designated States except US): LOCK-
HEED MARTIN CORPORATION [US/US]; 6801
Rockledge Drive, Bethesda, MD 20817-1803 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): RAPP, John
[US/US]; 9350 River Crest Rd., Manassas, VA 20110-7900

(US). HELLENBACH, Scott [US/US]; 15381 Quail Ridge Drive, Amissville, VA 20106-2205 (US). MATHUR, Chandan [US/US]; 11162 Privates Court, Manassas, VA 20109-7741 (US). JONES, Mark [US/US]; 15342 Oakmere Place, Centerville, VA 20120-1119 (US). CAPIZZI, Joseph, A. [US/US]; 16 Bedford Dr., Sterling, VA 20165-6008 (US). CHERASARO, Troy [US/US]; 215 Duke St., Apt K, Culpeper, VA 22701-1575 (US).

(74) Agent: RUSYN, Paul, F.; Graybeal Jackson Haley LLP, 155-108th Ave NE, Suite 350, Bellevue, WA 98004-5973 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KR, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TI, TM, TN, TR, TT, TZ, UA, UG, US (patent), UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TI, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: CONFIGURABLE COMPUTING MACHINE AND RELATED SYSTEMS AND METHODS

(57) Abstract: A computing machine includes programmable integrated circuits, a configuration registry, and a processor. The registry stores a file that defines a circuit having portions, and the processor is, in response to the file, operable to instantiate one of the circuit portions on one of the programmable integrated circuits. Consequently, by accessing a file that defines a circuit, such a computing machine can often instantiate the circuit on a pipeline accelerator regardless of the hardware that compose the accelerator and despite modifications to the circuit or to the hardware. That is, the computing machine can often "fit" the circuit into the pipeline accelerator regardless of its composition. A computing machine comprises an electronic circuit operable to perform a function, a programmable integrated circuit such as an FPGA, and a processor. The processor is operable to detect a failure of the electronic circuit and to configure the programmable integrated circuit to perform the function of the electronic circuit in response to detecting the failure. Alternatively, the computing machine comprises a hardwired pipeline operable to perform a function and a processor operable to detect a failure of the pipeline and to perform the function in response to detecting the failure. By allowing a first type of circuit (e.g., an FPGA) to take over for a failed second type of circuit (e.g., a processor), such a computing machine can be fault-tolerant without having redundant versions of each component, and may thus be less expensive and smaller than computing machines of comparable computing power. According to an embodiment of the invention, a computing machine comprises a pipeline accelerator, a host processor coupled to the pipeline scheme that is often more flexible than conventional schemes. For example, if the pipeline accelerator has more extra "space" than the host processor, then one can add to the computing machine one or more redundant pipeline units that can provide redundancy to both the pipeline and the host processor. Therefore, the computing machine can include redundancy for the host processor even though it has no redundant processing units.



WO 2006/039713 A2

CONFIGURABLE COMPUTING MACHINE AND RELATED SYSTEMS AND METHODS

CLAIM OF PRIORITY

[1] This application claims priority to U.S. Provisional Application
5 Serial Nos. 60/615,192, 60/615,157, 60/615,170, 60/615,158, 60/615,193,
and 60/615,050, filed on 01 October 2004, which are incorporated by
reference.

CROSS REFERENCE TO RELATED APPLICATIONS

[2] This application is related to U.S. Patent Application Serial
10 Nos. _____ (Attorney Docket
Nos. 1934-021-03, 1934-023-03, 1934-024-03, 1934-026-03, 1934-031-03,
1934-035-03, and 1934-036-03), which have a common filing date of 03
October 2005 and assignee and which are incorporated by reference.

BACKGROUND

15 [3] A peer-vector computing machine, which is described in the
following U.S. Patent Publications, includes a pipeline accelerator that can
often perform mathematical computations ten to one hundred times faster
than a conventional processor-based computing machine can perform
these computations: 2004/0133763; 2004/0181621; 2004/0136241;
20 2004/0170070; and, 2004/0130927, which are incorporated herein by
reference. The pipeline accelerator can often perform mathematical
computations faster than a processor because unlike a processor, the
accelerator processes data in a pipelined fashion while executing few, if
any, software instructions.

25 [4] Unfortunately, despite its oft-superior data-processing speed, a
peer-vector computing machine may lack some of the popular features of a
conventional processor-based computing machine.

[5] For example, a peer-vector computing machine may lack the ability to configure itself to operate with the installed hardware that composes the pipeline accelerator; and may lack the ability to reconfigure itself in response to a change in this hardware.

5 [6] Typically, a conventional processor-based computing machine can configure its software and settings during its start-up routine to operate with the hardware installed in the machine, and can also reconfigure its software and settings in response to a change in this hardware. For example, assume that while the processor-based machine is "off", one
10 increases the amount of the machine's random-access memory (RAM). During the next start-up routine, the machine detects the additional RAM, and reconfigures its operating system to recognize and exploit the additional RAM during subsequent operations. Similarly, assume that one adds a wireless-router card to the bus while the processor-based machine
15 is off. During the next start-up routine, the machine detects the card and configures its operating system to recognize and allow a software application such as a web browser to use the card (the machine may need to download the card's driver via a CD-ROM or the internet). Consequently, to install new hardware in a typical processor-based machine, an operator
20 merely inserts the hardware into the machine, which then configures or reconfigures the machine's software and settings without additional operator input.

[7] But a peer-vector machine may lack the ability to configure or reconfigure itself to operate the hardware that composes the pipeline
25 accelerator. For example, assume that one wants the peer-vector machine to instantiate a pre-designed circuit on multiple programmable-logic integrated circuits (PLICs) such as field-programmable gate arrays (FPGAs), each of which is disposed on a respective pipeline unit of the pipeline accelerator. Typically, one manually generates
30 configuration-firmware files for each of the PLICs, and loads these files into

the machine's configuration memory. During a start-up routine, the peer-vector machine causes each of the PLICs to download a respective one of these files. Once the PLICs have downloaded these firmware files, the circuit is instantiated on the PLICs. But if one modifies the circuit, or
5 modifies the type or number of pipeline units in the pipeline accelerator, then he may need to manually generate new configuration-firmware files and load them into the configuration memory before the machine can instantiate the modified circuit on the pipeline accelerator.

[8] Furthermore, the peer-vector computing machine may lack the
10 ability to continue operating if a component of the machine fails.

[9] Some conventional processor-based computing machines have redundant components that allow a machine to be fault tolerant, *i.e.*, to continue operating when a component fails or otherwise exhibits a fault or causes a fault in the machine's operation. For example, a multi-
15 processor-based computing machine may include a redundant processor that can "take over" for one of main processors if and when a main processor fails.

[10] But unfortunately, a peer-vector machine may have a lower level of fault tolerance than a fault-tolerant processor-based machine.

20 [11] Moreover, existing fault-tolerant techniques may add significant cost and complexity to a computing machine. Per the above example, assume that a processor-based computing machine includes a redundant processor. If the machine has only one main processor, then adding the redundant processor may double the area that the processors occupy, and
25 may double the costs for procuring and maintaining the processors.

[12] Therefore, a need has arisen for a peer-vector computing machine that can configure itself to operate with the hardware that composes the pipeline accelerator, and that can reconfigure itself to recognize and operate with newly modified accelerator installed hardware.

[13] A need has also arisen for a peer-vector machine having a higher level of fault tolerance.

[14] Furthermore, a need has arisen for a fault-tolerant technique that is less costly and complex than providing redundancy solely by the
5 inclusion of dedicated redundant components.

SUMMARY

[15] According to an embodiment of the invention, a computing machine includes programmable integrated circuits, a configuration registry, and a processor. The registry stores a file that defines a circuit having
10 portions, and the processor is, in response to the file, operable to instantiate one of the circuit portions on one of the programmable integrated circuits.

[16] Consequently, by accessing a file that defines a circuit, such a computing machine can often instantiate the circuit on a pipeline accelerator regardless of the hardware that composes the accelerator and
15 despite modifications to the circuit or to the hardware. That is, the computing machine can often "fit" the circuit into the pipeline accelerator regardless of its composition.

[17] According to an embodiment of the invention, a computing machine comprises an electronic circuit operable to perform a function, a
20 first programmable integrated circuit, and a first processor. The first processor is operable to detect a failure of the electronic circuit and configure the programmable integrated circuit to perform the function of the electronic circuit in response to detecting the failure.

[18] By allowing a first type of circuit to take over for a failed second
25 type of circuit, such a computing machine can be fault-tolerant without having redundant versions of each component. For example, such a computing machine allows a programmable integrated circuit such as a field-programmable gate array (FPGA) to "take over" for a failed electronic circuit such as another FPGA, an ASIC, or a processor. Consequently, by

allowing an FPGA to "take over" for an ASIC and for a processor, such a computing machine can omit a redundant ASIC and a redundant processor, and may thus allow a reduction in the cost and size of the computing machine.

5 [19] According to another embodiment of the invention, a computing machine comprises a hardwired pipeline operable to perform a function and a processor operable to detect a failure of the pipeline and perform the function in response to detecting the failure.

[20] By allowing processor to take over for a hardwired pipeline
10 disposed on, e.g., an FPGA, such a computing machine can omit redundant hardware, and may thus allow a reduction in the cost and size of the computing machine as described above.

[21] According to an embodiment of the invention, a computing machine comprises a pipeline accelerator, a host processor coupled to the
15 pipeline accelerator, and a redundant processor, a redundant pipeline unit, or both, coupled to the host processor and to the pipeline accelerator. The computing machine may also include a system-restore server and a system-restore bus that allow the machine to periodically save the machine states in case of a failure.

20 [22] Such a computing machine has a fault-tolerant scheme that is often more flexible than conventional schemes. For example, if the pipeline accelerator has more extra "space" than the host processor, then one can add to the computing machine one or more redundant pipeline units that can provide redundancy to both the pipeline and the host processor.

25 Therefore, the computing machine can include redundancy for the host processor even though it has no redundant processing units. Likewise, if the host processor has more extra "space" than the pipeline accelerator, then one can add to the computing machine one or more redundant processing units that can provide redundancy to both the pipeline and the
30 host processor.

BRIEF DESCRIPTION OF THE DRAWINGS

- [23] **FIG. 1** is a schematic block diagram of a peer-vector computing machine according to an embodiment of the invention.
- [24] **FIG. 2** is a schematic block diagram of a pipeline unit from the
5 pipelined accelerator of **FIG. 1** and including a PLIC according to an embodiment of the invention.
- [25] **FIG. 3** is a block diagram of the circuitry that composes the interface-adaptor and framework-services layers of the PLIC of **FIG. 2** according to an embodiment of the invention.
- 10 [26] **FIG. 4** is a block diagram of the accelerator/host-processor-configuration registry of **FIG. 1** according to an embodiment of the invention.
- [27] **FIG. 5** is a diagram of a hardware-description file that describes, in a top-down fashion the layers of circuitry to be instantiated on
15 a simple PLIC according to an embodiment of the invention.
- [28] **FIG. 6** is a block diagram of the accelerator-template library of **FIG. 4** according to an embodiment of the invention.
- [29] **FIG. 7** is a block diagram of the software-object library of **FIG. 4** according to an embodiment of the invention.
- 20 [30] **FIG. 8** is a block diagram of the circuit-definition library of **FIG. 4** according to an embodiment of the invention.
- [31] **FIG. 9** is a block diagram of the accelerator-firmware library of **FIG. 4** according to an embodiment of the invention.
- [32] **FIG. 10** is a functional block diagram of the host processor of
25 **FIG. 1** according to an embodiment of the invention.
- [33] **FIG. 11** is a schematic block diagram of a circuit defined by a file in the circuit-definition library of **FIGS. 4** and **8** for instantiation on the pipeline accelerator of **FIG. 1** according to an embodiment of the invention.

- [34] **FIG. 12** is a functional block diagram of the data paths between the PLICs of **FIG. 11** according to an embodiment of the invention.
- [35] **FIG. 13** is a schematic block diagram of the circuit of **FIG. 11** instantiated on fewer PLICs according to an embodiment of the invention.
- 5 [36] **FIG. 14** is a functional block diagram of the data paths between the portions of the circuit of **FIG. 11** instantiated on the pipeline accelerator of **FIG. 1** and a software-application thread that the processing unit of **FIG. 10** executes to perform the function of an un-instantiated portion of the circuit according to an embodiment of the invention.
- 10 [37] **FIG. 15** is block diagram of a peer-vector computing machine having redundancy according to an embodiment of the invention.
- [38] **FIG. 16** is a block diagram of a peer-vector computing machine having a system-restore server and a system-restore bus according to an embodiment of the invention.
- 15 [39] **FIG. 17** is a block diagram of a hardwired pipeline that includes a save/restore circuit according to an embodiment of the invention.
- [40] **FIG. 18** is a more-detailed block diagram of the hardwired pipeline of **FIG. 17** according to an embodiment of the invention.

DETAILED DESCRIPTION

20 Introduction

- [41] An accelerator-configuration manager that, according to embodiments of the invention, configures a peer-vector machine to operate with the hardware that composes the machine's pipeline accelerator and that reconfigures the machine to recognize and operate with newly modified
25 accelerator hardware are discussed below in conjunctions with **FIGS. 10 – 14**. And an accelerator-configuration registry that, according to embodiments of the invention, facilitate the configuration manager's ability

to configure and reconfigure the peer-vector machine is discussed below in conjunction with **FIGS. 4 – 9**.

[42] Furthermore, improved fault-tolerant techniques that, according to embodiments of the invention, allow a peer-vector machine to continue operating if a portion of the machine fails are discussed below in conjunction with **FIGS. 10 – 16**.

[43] But first is presented in conjunction with **FIGS. 1 – 3** an overview of peer-vector-machine concepts that should facilitate the reader's understanding of the above-mentioned configuration manager, configuration registry, and fault-tolerant techniques.

Overview Of Peer-Vector-Machine Concepts

[44] **FIG. 1** is a schematic block diagram of a computing machine **10**, which has a peer-vector architecture according to an embodiment of the invention. In addition to a host processor **12**, the peer-vector machine **10** includes a pipelined accelerator **14**, which is operable to process at least a portion of the data processed by the machine **10**. Therefore, the host-processor **12** and the accelerator **14** are "peers" that can transfer data messages back and forth. Because the accelerator **14** includes hardwired circuits (typically logic circuits) instantiated on one or more PLICs, it executes few, if any, program instructions, and thus for a given clock frequency, often performs mathematically intensive operations on data significantly faster than a bank of computer processors can. Consequently, by combining the decision-making ability of the processor **12** and the number-crunching ability of the accelerator **14**, the machine **10** has many of the same abilities as, but can often process data faster than, a conventional processor-based computing machine. Furthermore, as discussed below and in previously incorporated U.S. Patent Application Publication No. 2004/0136241, providing the accelerator **14** with a communication interface that is compatible with the interface of the host processor **12** facilitates the design and modification of the machine **10**, particularly where the

communication interface is an industry standard. And where the accelerator **14** includes multiple pipeline units (not shown in **FIG. 1**) which are sometimes called daughter cards, providing each of these units with this compatible communication interface facilitates the design and modification
5 of the accelerator, particularly where the communication interface is an industry standard. Moreover, the machine **10** may also provide other advantages as described in the following previously incorporated U.S. Patent Publication Nos.: 2004/0133763; 2004/0181621; 2004/0136241; 2004/0170070; and, 2004/0130927.

10 **[45]** Still referring to **FIG. 1**, in addition to the host processor **12** and the pipelined accelerator **14**, the peer-vector computing machine **10** includes a processor memory **16**, an interface memory **18**, a pipeline bus **20**, a firmware memory **22**, an optional raw-data input port **24**, an optional processed-data output port **26**, and an optional router **31**.

15 **[46]** The host processor **12** includes a processing unit **32** and a message handler **34**, and the processor memory **16** includes a processing-unit memory **36** and a handler memory **38**, which respectively serve as both program and working memories for the processor unit and the message handler. The processor memory **36** also includes an
20 accelerator/host-processor-configuration registry **40** and a message-configuration registry **42**. The registry **40** stores configuration data that allows a configuration manager (not shown in **FIG. 1**) executed by the host processor **12** to configure the functioning of the accelerator **14** and, in some situations as discussed below in conjunction with **FIGS. 10 – 14**,
25 the functioning of the host processor. Similarly, the registry **42** stores configuration data that allows the host processor **12** to configure the structure of the messages that the message handler **34** sends and receives, and the paths over which the message handler sends and receives these messages.

[47] The pipelined accelerator **14** includes at least one pipeline unit (not shown in **FIG. 1**) on which is disposed at least one PLIC (not shown in **FIG. 1**). On the at least one PLIC is disposed at least one hardwired pipeline, which processes data while executing few, if any, program instructions. The firmware memory **22** stores the configuration-firmware files for the PLIC(s) of the accelerator **14**. If the accelerator **14** is disposed on multiple PLICs, then these PLICs and their respective firmware memories may be disposed on multiple pipeline units. The accelerator **14** and pipeline units are discussed further in previously incorporated U.S. Patent Application Publication Nos. 2004/0136241, 2004/0181621, and 2004/0130927. The pipeline units are also discussed below in conjunction with **FIGS. 2 – 3**.

[48] Generally, in one mode of operation of the peer-vector computing machine **10**, the pipelined accelerator **14** receives data from one or more data-processor software applications running on the host processor **12**, processes this data in a pipelined fashion with one or more logic circuits that perform one or more mathematical operations, and then returns the resulting data to the data-processing application(s). As stated above, because the logic circuits execute few, if any, software instructions, they often process data one or more orders of magnitude faster than the host processor **12** can for a given clock frequency. Furthermore, because the logic circuits are instantiated on one or more PLICs, one can often modify these circuits merely by modifying the firmware stored in the memory **52**; that is, one can often modify these circuits without modifying the hardware components of the accelerator **14** or the interconnections between these components.

[49] The operation of the peer-vector machine **10** is further discussed in previously incorporated U.S. Patent Application Publication No. 2004/0133763, the functional topology and operation of the host processor **12** is further discussed in previously incorporated U.S. Patent

Application Publication No. 2004/0181621, and the topology and operation of the accelerator **14** is further discussed in previously incorporated U.S. Patent Application Publication No. 2004/0136241.

[50] **FIG. 2** is a schematic block diagram of a pipeline unit **50** of the
5 pipeline accelerator **14** of **FIG. 1** according to an embodiment of the invention.

[51] The unit **50** includes a circuit board **52** on which are disposed the firmware memory **22**, a platform-identification memory **54**, a bus connector **56**, a data memory **58**, and a PLIC **60**.

10 [52] As discussed above in conjunction with **FIG. 1**, the firmware memory **22** stores the configuration-firmware file that the PLIC **60** downloads to instantiate one or more logic circuits, at least some of which compose the hardwired pipelines (**44**).

[53] The platform memory **54** stores one or more values, *i.e.*,
15 platform identifiers, that respectively identify the one or more platforms with which the pipeline unit **50** is compatible. Generally, a platform specifies a unique set of physical attributes that a pipeline unit may possess. Examples of these attributes include the number of external pins (not shown) on the PLIC **60**, the width of the bus connector **56**, the size of the
20 PLIC, and the size of the data memory **58**. Consequently, a pipeline unit **50** is compatible with a platform if the unit possesses all of the attributes that the platform specifies. So a pipeline unit **50** having a bus connector **56** with thirty two bits is incompatible with a platform that specifies a bus connector with sixty four bits. Some platforms may be compatible with the peer vector
25 machine **10** (**FIG. 1**), and others may be incompatible. Consequently, the platform identifier(s) stored in the memory **54** may allow a configuration manager (not shown in **FIG. 2**) executed by the host processor **12** (**FIG. 1**) to determine whether the pipeline unit **50** is compatible with the platform(s) supported by the machine **10**. And where the pipeline unit **50** is so
30 compatible, the platform identifier(s) may also allow the configuration

manager to determine how to configure the PLIC **60** or other portions of the pipeline unit as discussed below in conjunction with **FIGS. 10 – 14**.

[54] The bus connector **56** is a physical connector that interfaces the PLIC **60**, and perhaps other components of the pipeline unit **50**, to the pipeline bus **20** (**FIG. 1**).

[55] The data memory **58** acts as a buffer for storing data that the pipeline unit **50** receives from the host processor **12** (**FIG. 1**) and for providing this data to the PLIC **60**. The data memory **58** may also act as a buffer for storing data that the PLIC **60** generates for sending to the host processor **12**, or as a working memory for the hardwired pipeline(s) **44**.

[56] Instantiated on the PLIC **60** are logic circuits that compose the hardwired pipeline(s) **44**, and a hardware interface layer **62**, which interfaces the hardwired pipeline(s) to the external pins (not shown) of the PLIC **60**; and which thus interfaces the pipeline(s) to the pipeline bus **20** (via the connector **56**), to the firmware and platform-identification memories **22** and **54**, and to the data memory **58**. Because the topology of the interface layer **62** is primarily dependent upon the attributes specified by the platform(s) with which the pipeline unit **50** is compatible, one can often modify the pipeline(s) **44** without modifying the interface layer. For example, if a platform with which the unit **50** is compatible specifies a thirty-two bit bus, then the interface layer **62** provides a thirty-two-bit bus connection to the bus connector **56** regardless of the topology or other attributes of the pipeline(s) **44**.

[57] The hardware-interface layer **62** includes three circuit layers that are instantiated on the PLIC **60**: an interface-adapter layer **70**, a framework-services layer **72**, and a communication layer **74**, which is hereinafter called a communication shell. The interface-adapter layer **70** includes circuitry, e.g., buffers and latches, that interface the framework-services layer **72** to the external pins (not shown) of the PLIC **60**. The framework-services layer **72** provides a set of services to the

hardwired pipeline(s) **44** via the communication shell **74**. For example, the layer **72** may synchronize data transfer between the pipeline(s) **44**, the pipeline bus **20** (**FIG. 1**), and the data memory **58** (**FIG. 2**), and may control the sequence(s) in which the pipeline(s) operate. The communication shell
5 **74** includes circuitry, e.g., latches, that interface the framework-services layer **72** to the pipeline(s) **44**.

[58] Still referring to **FIG. 2**, alternate embodiments of the pipeline unit **50** are contemplated. For example, the memory **54** may be omitted, and the platform identifier(s) may be stored in the firmware memory **22**, or by a
10 jumper-configurable or hardwired circuit (not shown) disposed on the circuit board **52**. Furthermore, although the framework-services layer **72** is shown as isolating the interface-adapter layer **70** from the communication shell **74**, the interface-adapter layer may, at least at some circuit nodes, be directly coupled to the communication shell. Furthermore, although the
15 communication shell **74** is shown as isolating the interface-adapter layer **70** and the framework-services layer **72** from the pipeline(s) **44**, the interface-adapter layer or the framework-services layer may, at least at some circuit nodes, be directly coupled to the pipeline(s).

[59] A pipeline unit similar to the unit **50** is discussed in previously
20 incorporated U.S. Patent Application Publication No. 2004/0136241.

[60] **FIG. 3** is a schematic block diagram of the circuitry that composes the interface-adapter layer **70** and the framework-services layer **72** of **FIG. 2** according to an embodiment of the invention.

[61] A communication interface **80** and an optional
25 industry-standard bus interface **82** compose the interface-adapter layer **70**, and a controller **84**, exception manager **86**, and configuration manager **88** compose the framework-services layer **72**. The configuration manager **88** is local to the PLIC **60**, and is thus different from the configuration manager executed by the host processor **12** as discussed above in conjunction with
30 **FIG. 1** and below in conjunction with **FIGS. 10 – 14**.

[62] The communication interface **80** transfers data between a peer, such as the host processor **12** (**FIG. 1**) or another pipeline unit **50** (**FIG. 2**), and the firmware memory **22**, the platform-identifier memory **54**, the data memory **58**, and the following circuits instantiated within the PLIC **60**: the
5 hardwired pipeline(s) **44** (via the communication shell **74**), the controller **84**, the exception manager **86**, and the configuration manager **88**. If present, the optional industry-standard bus interface **82** couples the communication interface **80** to the bus connector **56**. Alternatively, the interfaces **80** and **82** may be merged such that the functionality of the interface **82** is included
10 within the communication interface **80**.

[63] The controller **84** synchronizes the hardwired pipeline(s) **44** and monitors and controls the sequence in which it/they perform the respective data operations in response to communications, *i.e.*, "events," from other peers. For example, a peer such as the host processor **12** may
15 send an event to the pipeline unit **50** via the pipeline bus **20** to indicate that the peer has finished sending a block of data to the pipeline unit and to cause the hardwired pipeline(s) **44**, to begin processing this data. An event that includes data is typically called a message, and an event that does not include data is typically called a "door bell."

[64] The exception manager **86** monitors the status of the hardwired pipeline(s) **44**, the communication interface **80**, the communication shell **74**, the controller **84**, and the bus interface **82** (if present), and reports exceptions to another exception manager (not shown in **FIG. 3**) the host processor **12** (**FIG. 1**). For example, if a buffer (not shown) in the
20 communication interface **80** overflows, then the exception manager **86** reports this to the host processor **12**. The exception manager may also correct, or attempt to correct, the problem giving rise to the exception. For example, for an overflowing buffer, the exception manager **86** may increase the size of the buffer, either directly or via the configuration manager **88** as
25 discussed below.
30

[65] The configuration manager **88** sets the "soft" configuration of the hardwired pipeline(s) **44**, the communication interface **80**, the communication shell **74**, the controller **84**, the exception manager **86**, and the interface **82** (if present) in response to soft-configuration data from the host processor **12** (**FIG. 1**). As discussed in previously incorporated U.S. Patent Application Publication No. 2004/0133763, the "hard" configuration of a circuit within the PLIC **60** denotes the actual instantiation, on the transistor and circuit-block level, of the circuit, and the soft configuration denotes the settable physical parameters (e.g., data type, table size buffer depth) of the instantiated component. That is, soft-configuration data is similar to the data that one can load into a register of a processor (not shown in **FIG. 3**) to set the operating mode (e.g., burst-memory mode, page mode) of the processor. For example, the host processor **12** may send to the PLIC **60** soft-configuration data that causes the configuration manager **88** to set the number and respective priority levels of queues (not shown) within the communication interface **80**. And as discussed in the preceding paragraph, the exception manager **86** may also send soft-configuration data that causes the configuration manager **88** to, e.g., increase the size of an overflowing buffer in the communication interface **80**.

[66] The communication interface **80**, optional industry-standard bus interface **82**, controller **84**, exception manager **86**, and configuration manager **88** are further discussed in previously incorporated U.S. Patent Application Publication No. 2004/0136241.

[67] Referring again to **FIGS. 2 – 3**, although the pipeline unit **50** is disclosed as including only one PLIC **60**, the pipeline unit may include multiple PLICs. For example, as discussed in previously incorporated U.S. Patent Application Publication No. 2004/0136241, the pipeline unit **50** may include two interconnected PLICs, where the circuitry that composes the interface-adaptor layer **70** and framework-services layer **72** are instantiated

on one of the PLICs, and the circuitry that composes the communication shell **74** and the hardwired pipeline(s) **44** are instantiated on the other PLIC.

[68] **FIG. 4** is a block diagram of the accelerator/host-processor configuration registry **40** of **FIG. 1** according to an embodiment of the invention.

[69] The registry **40** includes configuration data **100**, an accelerator-template library **102**, a software-object library **104**, a circuit-definition library **106**, and an accelerator-firmware library **108**.

[70] The configuration data **100** contains instructions that the configuration manager (not shown in **FIG. 4**) executed by the host processor **12** (**FIG. 1**) follows to configure the accelerator **14** (**FIG. 1**), and is further discussed below in conjunction with **FIGS. 10 – 14**. These instructions may be written in any conventional language or format.

[71] The accelerator-template library **102** contains templates that define one or more interface-adaptor layers **70**, framework-services layers **72**, communication shells **74**, and hardwired pipelines **44** that the configuration manager executed by the host processor **12** (**FIG. 1**) can instantiate on the PLICs **60** (**FIG. 2**). The library **102** is further discussed below in conjunction with **FIGS. 5 – 6**.

[72] The software-object library **104** contains one or more software objects that, when executed, respectively perform in software the same (or similar) functions that the pipelines **44** defined by the templates in the accelerator-template library **102** perform in hardware. These software objects give the configuration manager executed by the host processor **12** the flexibility of instantiating in software at least some of the pipelined functions specified by the configuration data **100**. The library **104** is further discussed below in conjunction with **FIG. 7**.

[73] The circuit-definition library **106** contains one or more circuit-definition files that each define a respective circuit for instantiation on

the accelerator **14** (**FIG. 1**). Each circuit typically includes one or more interconnected hardwired pipelines **44** (**FIG. 1**), which are typically defined by corresponding templates in the library **102**. The library **106** is further discussed below in conjunction with **FIG. 8**.

5 [74] The accelerator-firmware library **108** contains one or more firmware-configuration files that each PLIC **60** (**FIG. 2**) of the accelerator **14** (**FIG. 1**) respectively downloads to set its internal circuit-node connections so as to instantiate a respective interface-adapter layer **70**, framework-services layer **72**, communication shell **74**, and hardwired
10 pipeline(s) **44**. The library **108** is further discussed below in conjunction with **FIG. 9**.

[75] **FIG. 5** is a block diagram of a hardware-description file **120** from which the configuration manager (not shown in **FIG. 5**) executed by the host processor **12** (**FIG. 1**) can generate firmware for setting the circuit-
15 node connections within a PLIC such as the PLIC **60** (**FIGS. 2 – 3**) according to an embodiment of the invention. The accelerator-template library **102** contains templates that one can arrange to compose the file **120**; consequently, an understanding of the hardware-description file **120** should facilitate the reader's understanding of the accelerator-template
20 library **102**, which is discussed below in conjunction with **FIG. 6**.

[76] Typically, the below-described templates of the hardware-description file **120** are written in a conventional hardware description language (HDL) such as Verilog® HDL, and are organized in a top-down structure that resembles the top-down structure of software
25 source code that incorporates software objects. A similar hardware-description file is described in previously incorporated U.S. Patent App. Ser. No. _____ (Attorney Docket No. 1934-023-03). Furthermore, techniques for generating PLIC firmware from the file **120** are discussed below in conjunction with **FIGS. 10 – 14**.

[77] The hardware-description file **120** includes a top-level template **121**, which contains respective top-level definitions **122**, **124**, and **126** of the interface-adapter layer **70**, the framework-services layer **72**, and the communication shell **74** — together, the definitions **122**, **124**, and **126** compose a top-level definition **123** of the hardware-interface layer **62** — of a PLIC such as the PLIC **60** (**FIGS. 2 – 3**). The template **121** also defines the connections between the external pins (not shown) of the PLIC and the interface-adapter layer **70** (and in some cases between the external pins and the framework-services layer **72**), and also defines the connections between the framework-services layer and the communication shell **74** (and in some cases between the interface-adapter layer and the communication shell).

[78] The top-level definition **122** of the interface-adapter layer **70** (**FIGS. 2 – 3**) incorporates an interface-adapter-layer template **128**, which further defines the portions of the interface adapter layer defined by the top-level definition **122**. For example, suppose that the top-level definition **122** defines a data-input buffer (not shown) in terms of its input and output nodes. That is, suppose the top-level definition **122** defines the data-input buffer as a functional block having defined input and output nodes. The template **128** defines the circuitry that composes this functional buffer block, and defines the connections between this circuitry and the buffer input nodes and output nodes already defined by in the top-level definition **122**. Furthermore, the template **128** may incorporate one or more lower-level templates **129** that further define the data buffer or other components of the interface-adapter layer **70** already defined in the template **128**. Moreover, these one or more lower-level templates **129** may each incorporate one or more even lower-level templates (not shown), and so on, until all portions of the interface-adapter layer **70** are defined in terms of circuit components (e.g., flip-flops, logic gates) that a PLIC synthesizing and routing tool (not shown) recognizes — a PLIC synthesizing and routing tool is a

conventional tool, typically provided by the PLIC manufacturer, that can generate from the hardware-description file **120** configuration firmware for a PLIC.

[79] Similarly, the top-level definition **124** of the framework-services layer **72** (**FIGS. 2 – 3**) incorporates a framework-services-layer template **130**, which further defines the portions of the framework-services layer defined by the top-level definition **124**. For example, suppose that the top-level definition **124** defines a counter (not shown) in terms of its input and output nodes. The template **130** defines the circuitry that composes this counter, and defines the connections between this circuitry and the counter input and output nodes already defined in the top-level definition **124**. Furthermore, the template **130** may incorporate a hierarchy of one or more lower-level templates **131** and even lower-level templates (not shown), and so on such that all portions of the framework-services layer **72** are, at some level of the hierarchy, defined in terms of circuit components (e.g., flip-flops, logic gates) that the PLIC synthesizing and routing tool recognizes. For example, suppose that the template **130** defines the counter as including a count-up/down selector having input and output nodes. The template **130** may incorporate a lower-level template **131** that defines the circuitry within this up/down selector and the connections between this circuitry and the selector's input and output nodes already defined by the template **130**.

[80] Likewise, the top-level definition **126** of the communication shell **74** (**FIGS. 2 – 3**) incorporates a communication-shell template **132**, which further defines the portions of the communication shell defined by the definition **126**, and which also includes a top-level definition **133** of the hardwired pipeline(s) **44** disposed within the communication shell. For example, the definition **133** defines the connections between the communication shell **74** and the hardwired pipeline(s) **44**.

- [81] The top-level definition **133** of the pipeline(s) **44** (**FIGS. 2 – 3**) incorporates for each defined pipeline a respective hardwired-pipeline template **134**, which further defines the portions of the respective pipeline **44** already defined by the definition **133**. The template or templates **134** may each incorporate a hierarchy of one or more lower-level templates **135**, and even lower-level templates, such that all portions of the respective pipeline **44** are, at some level of the hierarchy, defined in terms of circuit components (e.g., flip-flops, logic gates) that the PLIC synthesizing and routing tool recognizes.
- 10 [82] Moreover, the communication-shell template **132** may incorporate a hierarchy of one or more lower-level templates **136**, and even lower-level templates, such that all portions of the communication shell **74** other than the pipeline(s) **44** are, at some level of the hierarchy, also defined in terms of circuit components (e.g., flip-flops, logic gates) that the
- 15 PLIC synthesizing and routing tool recognizes.
- [83] Still referring to **FIG. 5**, a configuration template **138** provides definitions for one or more parameters having values that one can set to configure the circuitry that the templates **121**, **128**, **129**, **130**, **131**, **132**, **134**, **135**, and **136**, and the even lower-level templates (not shown) define. For
- 20 example, suppose that the bus interface **82** (**FIG. 3**) of the interface-adaptor layer **70** (**FIG. 3**) is configurable to have either a thirty-two-bit or a sixty-four-bit interface to the bus connector **56**. The configuration template **138** defines a parameter BUS-WIDTH, the value of which determines the width of the interface **82**. For example, BUS-WIDTH = 0 configures the interface
- 25 **82** to have a thirty-two-bit interface, and BUS-WIDTH = 1 configures the interface **82** to have a sixty-four-bit interface. Examples of other parameters that may be configurable in this manner include the depth of a first-in-first-out (FIFO) data buffer (not shown) disposed within the data memory **58** (**FIGS. 2 – 3**), the lengths of messages received and
- 30 transmitted by the interface adapter layer **70**, the precision and data type

(e.g., integer, floating-point) of the pipeline(s) **44**, and a constant coefficient of a mathematical expression (e.g., "a" in ax^2) that a pipeline executes.

[84] One or more of the templates **121**, **128**, **129**, **130**, **131**, **132**, **134**, **135**, and **136** and the lower-level templates (not shown) incorporate the parameter(s) defined in the configuration template **138**. The PLIC synthesizer and router tool (not shown) configures the interface-adaptor layer **70**, the framework-services layer **72**, the communication shell **74**, and the hardwired pipeline(s) **44** (FIGS. 2 – 3) according to the set values in the template **138** during the synthesis of the hardware-description file **120**.
Consequently, to reconfigure the circuit parameters associated with the parameters defined in the configuration template **138**, one need only modify the values of these parameters in the configuration template, and then rerun the synthesizer and router tool on the file **120**. Alternatively, if one or more of the parameters in the configuration template **138** can be sent to the PLIC as soft-configuration data after instantiation of the circuit, then one can modify the corresponding circuit parameters by merely modifying the soft-configuration data. Therefore, according to this alternative, may avoid rerunning the synthesizer and router tool on the file **120**. Moreover, templates (e.g., **121**, **128**, **129**, **130**, **131**, **132**, **134**, **135**, and **136**) that do not incorporate settable parameters such as those provided by the configuration template **138** are sometimes called modules or entities, and are typically lower-level templates that include Boolean expressions that a synthesizer and router tool (not shown) converts into circuitry for implementing the expressions.

[85] Alternate embodiments of the hardware-description file **120** are contemplated. For example, although described as defining circuitry for instantiation on a PLIC, the file **120** may define circuitry for instantiation on an application-specific integrated circuit (ASIC).

[86] FIG. 6 is a block diagram of the accelerator-template library **102** of FIG. 4 according to an embodiment of the invention. The library **102**

contains one or more versions of the templates described above in conjunction with **FIG. 5**. For clarity, however, the optional lower-level templates **129**, **131**, **135**, and **136** are omitted from **FIG. 6**. Furthermore, a library similar to the library **102** is described in previously incorporated U.S. Patent App. Ser. No. _____ (Attorney Docket No. 1934-023-03).

[87] The library **102** has $m+1$ sections: m sections **140₁** – **140_m** for the respective m platforms that the library supports, and a section **142** for the hardwired pipelines **44** (**FIGS. 1 – 3**) that the library supports.

[88] For example purposes, the library section **140₁** is discussed in detail, it being understood that the other library sections **140₂** – **140_m** are similar.

[89] The library section **140₁** includes a top-level template **121₁**, which is similar to the template **121** of **FIG. 5**, and which thus includes top-level definitions **122₁**, **124₁**, and **126₁** of the respective versions of the interface-adapter layer (IAL) **70**, the framework-services layer (FSL) **72**, and the communication shell(s) **74** (**FIGS. 2 – 3**) that are compatible with the platform $m=1$, i.e., platform 1.

[90] In this embodiment, we assume that there is only one version of the interface-adapter layer **70** and one version of the framework services layer **72** (**FIGS. 2 – 3**) available for each platform m , and, therefore, that the library section **140₁** includes only one interface-adapter-layer template **128₁** and only one framework-services-layer template **130₁**. But in an embodiment where each platform m includes multiple versions of the interface-adapter layer **70** and multiple versions of the framework-services layer **72**, the library section **140₁** would include multiple interface-adapter- and framework-services-layer templates **128** and **130**.

[91] The library section **140₁** also includes n communication-shell templates **132_{1,1}** – **132_{1,n}**, which respectively correspond to the hardwired-pipeline templates **134₁** – **134_n** in the library section **142**. As stated above

in conjunction with **FIGS. 2 – 3**, the communication shell **74** interfaces a
hardwired pipeline or hardwired-pipelines **44** to the framework-services
layer **72**. Because each hardwired pipeline **44** is different and, therefore,
typically has different interface specifications, the communication shell **74** is
5 typically different for each hardwired pipeline. Consequently, in this
embodiment, one provides design adjustments to create a unique version
of the communication shell **74** for each hardwired pipeline **44**. The designer
provides these design adjustments by writing a unique communication-shell
template **132** for each hardwired pipeline. Of course the group of
10 communication-shell templates **132_{1,1} – 132_{1,n}** corresponds only to the
version of the framework-services layer **72** that is defined by the template
130_i; consequently, if there are multiple versions of the framework-services
layer **72** that are compatible with the platform 1, then the library section
140_i includes a respective group of *n* communication-shell templates **132**
15 for each version of the framework-services layer.

[92] Furthermore, the library section **140_i** includes a configuration
template **138_i**, which defines for the other templates in this library section
(and possibly for the hardwired-pipeline templates **134** in the section **142**)
configuration constants having designer-selectable values as discussed
20 above in conjunction with the configuration template **138** of **FIG. 5**.

[93] In addition, each template within the library section **140_i**
includes, or is associated with, a respective template description **144_i –**
152_i. The descriptions **144_i – 150_{i,n}** describe the operational and other
parameters of the circuitry that the respective templates **121_i, 128_i, 130_i,**
25 and **132_{1,1} – 132_{1,n}** respectively define. Similarly, the template description
152_i describes the settable parameters in the configuration template **138_i,**
the values that these parameters can have, and the meanings of these
values. Examples of parameters that a template description **144_i – 150_{i,n}**
may describe include the width of the data bus and the depths of FIFO
30 buffers that the circuit defined by the corresponding template includes, the

latency of the circuit, and the type and precision of the values received and generated by the circuit. An example of a settable parameter and the associated selectable values that the description **152_i** may describe is **BUS_WIDTH**, which represents the width of the interface between the communication interface **80** and the bus connector **56** (**FIGS. 2 – 3**), where **BUS_WIDTH = 0** sets this interface to thirty-two bits and **BUS_WIDTH = 1** sets this interface to sixty-four bits.

[94] Each of the template descriptions **144_i – 152_i** may be embedded within the template **121_i**, **128_i**, **130_i**, **132_i – 132_{i,n}**, and **138_i** to which it corresponds. For example, the IAL template description **146_i** may be embedded within the interface-adaptor-layer template **128_i** as extensible markup language (XML) tags or comments that are readable by both a human and the host processor **12** (**FIG. 1**) as discussed below in conjunction with **FIGS. 10 – 14**.

[95] Alternatively, each of the template descriptions **144_i – 152_i** may be disposed in a separate file that is linked to the template to which the description corresponds, and this file may be written in a language other than XML. For example, the top-level-template description **144_i** may be disposed in a file that is linked to the top-level template **121_i**.

[96] The section **140_i** of the library **102** also includes a description **154_i**, which describes parameters specified by of the platform $m = 1$. The host processor **12** (**FIG. 1**) may use the description **154_i** to determine which platform(s) the library **102** supports as discussed below in conjunction with **FIGS. 10 – 14**. Examples of parameters that the description **154_i** may describe include: 1) for each interface, the message specification, which lists the transmitted variables and the constraints for those variables, and 2) a behavior specification and any behavior constraints. Messages that the host processor **12** (**FIG. 1**) sends to the pipeline units **50** (**FIG 2**) and that the pipeline units send among themselves are further discussed in previously incorporated U.S. Patent Publication No. 2004/0181621.

Examples of other parameters that the description **154_i** may describe include the size and resources (e.g., the number of multipliers and the amount of available memory) that the platform specifies for the PLICs that compose a compatible pipeline accelerator **14** (**FIG. 1**). Furthermore, like
 5 the template descriptions **144_i – 152_{i,n}**, the platform description **154_i** may be written in XML or in another language.

[97] Still referring to **FIG. 6**, the section **142** of the library **102** includes n hardwired-pipeline templates **134_i – 134_n**, which each define a respective hardwired pipeline **44_i – 44_n** (**FIGS. 1 – 3**). As discussed above
 10 in conjunction with **FIG. 5**, because the templates **134_i – 134_n** are platform independent (the corresponding communication-shell templates **132_{m,1} – 132_{m,n}** respectively define the specified interfaces between the pipelines **44** and the framework-services layer **70**, the library **102** stores only one template **134** for each hardwired pipeline **44**. That is, each hardwired
 15 pipeline **44** does not require a separate template **134** for each platform m that the library **102** supports. As discussed in previously incorporated U.S. Patent Application Ser. No. _____ (Attorney Docket No. 1934-023-03), an advantage of this top-down design is that one need generate only a single template **134** to define a respective hardwired pipeline **44**, not m
 20 templates.

[98] Furthermore, each hardwired-pipeline template **134** includes, or is associated with, a respective template description **156_i – 156_n**, which describes parameters of the hardwired-pipeline **44** that the template defines. Examples of parameters that a template description **156_i – 156_n**
 25 may describe include the type (e.g., floating point or integer) and precision of the data values that the corresponding hardwired pipeline **44** can receive and generate, and the latency of the pipeline. Like the template descriptions **144_i – 152_i**, each of the descriptions **156_i – 156_n** may be respectively embedded within the hardwired-pipeline template **134_i – 134_n**
 30 to which the description corresponds as, e.g., XML tags, or may be

disposed in a separate file that is linked to the corresponding hardwired-pipeline template.

[99] Still referring to **FIG. 6**, alternate embodiments of the library **102** are contemplated. For example, instead of each template within each library section **140₁ – 140_m** being associated with a respective description **144 – 152**, each library section **140₁ – 140_m** may include a single description that describes all of the templates within that library section. For example, this single description may be embedded within or linked to the top-level template **121** or to the configuration template **138**. Furthermore, although each library section **140₁ – 140_m** is described as including a respective communication-shell template **132** for each hardwired-pipeline template **134** in the library section **142**, each section **140** may include fewer communication-shell templates, at least some of which are compatible with, and thus correspond to, more than one pipeline template **134**. In an extreme, each library section **140₁ – 140_m** may include only a single communication-shell template **132**, which is compatible with all of the hardwired-pipeline templates **134** in the library section **142**. In addition, the library section **142** may include respective versions of each pipeline template **134** for each communication-shell template **132** in the library sections **140₁ – 140_m**.

[100] **FIG. 7** is a block diagram of the software-object library **104** of **FIG. 4** according to an embodiment of the invention.

[101] The library **104** includes software objects **160₁ – 160_q**, at least some of which can cause the host processor **12** (**FIG. 1**) to perform in software the same functions that respective ones of the hardwired pipelines **44₁ – 44_n** (**FIGS. 2 – 3**) can perform in hardware. For example, if the pipeline **44₁** squares a value v (v^2) input to the pipeline, then a corresponding software object **160₁** can cause the host processor **12** to square an input value v (v^2). The software objects **160₁ – 160_q** may be directly executable by the host processor **12**, or may cause the host

processor to generate corresponding programming code that the host processor can execute. Furthermore, the software objects **160₁ – 160_q** may be written in any conventional programming language such as C⁺⁺.

Because object-oriented software architectures are known, further details of the software objects **160** are omitted for brevity.

[102] The library **104** also includes respective object descriptions **162₁ – 162_q** of the software objects **160₁ – 160_q**. The object descriptions **162** may describe parameters and other features of the software objects **160**, such as the function(s) that they cause the host processor **12** (**FIG. 1**) to perform, and the latency and the type and precision of the values accepted and generated by the host processor **12** while performing the function(s). Furthermore, the descriptions **162** may be written in a conventional language, such as XML, that the host processor **12** recognizes, and may be embedded, e.g., as comment tags, within the respective software objects **160** or may be contained within separate files that correspond to the respective software objects.

[103] Referring to **FIGS. 1** and **7**, as discussed below in conjunction with **FIGS. 10 – 14**, the software objects **160** provide the host processor **12** flexibility in configuring the pipeline accelerator **14**, and in reconfiguring the peer-vector machine **10** in the event of a failure. For example, suppose that the configuration data **100** calls for instantiating eight hardwired pipelines **44** on the accelerator **14**, but the accelerator has room for only seven pipelines. The host processor **12** may execute a software object that corresponds to the eighth pipeline so as to perform the function that the eighth pipeline otherwise would have performed. Or, suppose that the configuration data **100** calls for instantiating a pipeline **44** that performs a function (e.g., sin (v)), but no such pipeline is available. The host processor **12** may execute a software object **160** so as to perform the function.

[104] **FIG. 8** is a block diagram of the circuit-definition library **106** of **FIG. 4** according to an embodiment of the invention.

[105] The library **106** includes circuit-definition files **170₁ – 170_p**, which each define a respective circuit for instantiation on one more PLICs (**FIGS. 2 – 3**) of the pipeline accelerator **14** (**FIG. 1**) in terms of templates from the accelerator-template library **102** (**FIG. 4**). To define a circuit for
5 instantiation on a single PLIC, the circuit file **170** identifies from the template library **102** (**FIGS. 4** and **6**) the respective top-level template **121**, interface-adaptor-layer template **128**, framework-services-layer template **130**, communication-shell template **132**, hardwired-pipeline-template(s) **134**, configuration template **138**, and corresponding lower-level templates
10 that define the circuitry to be instantiated on that PLIC. And if the PLIC is to include multiple hardwired-pipelines **44**, then the file **170** defines the interconnections between these pipelines. To define a circuit for instantiation on multiple PLICs, the circuit file **170** identifies for each PLIC the templates that define the circuitry to be instantiated on that PLIC, and
15 also defines the interconnections between the PLICs. An example of a circuit defined by a circuit file **170** is described below in conjunction with **FIG. 11**.

[106] The library **106** also includes circuit descriptions **172₁ – 172_p** that correspond to the circuit-definition files **170₁ – 170_p**. A description **172**
20 typically describes the function (e.g., $y = x^2 + z^3$) performed by the circuit that the corresponding file **170** detects, and the operating parameters and other features of the circuit, such as the latency and the type and precision of the values accepted and generated by each PLIC that composes the circuit. The description **172** may also identify the platform(s) with which the
25 corresponding circuit is compatible, and may include values for the constants defined by the configuration template(s) **138** (**FIGS. 5 – 6**) that the circuit definition file **170** identifies. Furthermore, each of the circuit descriptions **170** may be written in a conventional language, such as XML, that the host processor **12** (**FIG. 1**) recognizes, and may be embedded
30 (e.g., as comment tags) within a respective circuit-description file **170** or

may be contained within a separate file that is linked to the respective circuit-description file.

[107] Files similar to the circuit-definition files **170** and a tool for generating these files are disclosed in previously incorporated U.S. Patent Application _____ (Attorney Docket No. 1934-023-03). Furthermore, although described as defining circuits for instantiation on one or more PLICs, some of the circuit-definition files **170** may define circuits for instantiation on an ASIC.

[108] **FIG. 9** is a block diagram of the accelerator-firmware library **108** of **FIG. 4** according to an embodiment of the invention.

[109] The library **108** includes firmware files **180₁ – 180_n**, each of which, when downloaded by a PLIC, configures the PLIC to instantiate a respective circuit. As described above in conjunction with **FIGS. 2 – 3**, the respective circuit typically includes an interface-adaptor layer **70**, framework-services layer **72**, communication shell **74**, and one or more hardwired pipelines **44**, although the circuit may have a different topology. A PLIC synthesizing and routing tool (not shown) may generate one or more of the firmware files **180** from templates in the accelerator-template library **102** (**FIG. 4**), or in another manner.

[110] The firmware files **180₁ – 180_n** are the only files within the accelerator/host-processor-configuration registry **40** (**FIG. 4**) that can actually configure a PLIC to instantiate a circuit. That is, although the templates in the library **102** (**FIG. 4**) and the circuit-definition files **170** in the library **106** (**FIG. 4**) define circuits, the configuration manager (not shown in **FIG. 9**) executed by the host processor **12** (**FIG. 1**) cannot instantiate such a defined circuit on the pipeline accelerator **14** (**FIG. 1**) until the respective template(s) and/or circuit-definitions files are converted into one or more corresponding firmware files **180** using, for example, a PLIC synthesizing and routing tool (not shown).

[111] Still referring to **FIG. 9**, the library **108** also includes respective descriptions **182₁ – 182_r** of the firmware files **180₁ – 180_r**. Each description **182** typically describes the function (e.g., $y = x^2 + z^3$) performed by the circuit that the corresponding firmware file **180** can instantiate, and the parameters and other features of the circuit, such as the latency and the type and precision of the values accepted and generated by the circuit. The description **182** may also identify the platform(s) with which the corresponding circuit is compatible, and may also identify the type(s) of PLIC on which the circuit can be instantiated. Furthermore, the descriptions **182** may be written in a conventional language, such as XML, that the host processor **12** (**FIG. 1**) recognizes, and may be embedded (e.g., as comment tags) within the respective firmware files **180** or may be contained within separate files that are linked to the respective firmware files.

[112] **FIG. 10** is a functional block diagram of the host processor **12**, the interface memory **18**, and the pipeline bus **20** of **FIG. 1** according to an embodiment of the invention. Generally, the processing unit **32** executes one or more software applications, and the message handler **34** executes one or more software objects (different from the software objects in the library **104** of **FIG. 4**) that transfer data between the software application(s) and the pipeline accelerator **14** (**FIG. 1**). Splitting the data-processing, data-transferring, and other functions among different applications and objects allows for easier design and modification of the host-processor software. Furthermore, although in the following description a software application is described as performing a particular function, it is understood that in actual operation, the processing unit **32** or message handler **34** executes the software application and performs this function under the control of the application. Moreover, although in the following description a software object is described as performing a particular function, it is understood that in actual operation, the processing unit **32** or message handler **34** executes the software object and performs this function under the control of the object. In addition, although in the following description a

manager application (e.g., configuration manager) is described as performing a particular function, it is understood that in actual operation, the processing unit **32** or message handler **34** executes the manager application and performs this function under the control of the manager application.

[113] Still referring to **FIG. 10**, the processing unit **32** executes at least one data-processing application **190**, an accelerator-exception-manager application (hereinafter the exception manager) **192**, and an accelerator-configuration-manager application (hereinafter the configuration manager) **194**, which are collectively referred to as the processing-unit applications. Furthermore, the exception and configuration managers **192** and **194** are executed by the processing unit **32**, and are thus different from the exception and configuration managers **88** and **90** disposed on the PLIC **60** of **FIG. 3**.

[114] The data-processing application **190** processes data in cooperation with the pipeline accelerator **14** (**FIG. 1**). For example, the data-processing application **190** may receive raw sonar data via the port **24**, parse the data, and send the parsed data to the accelerator **14**, and the accelerator may perform a fast Fourier transform (FFT) on the parsed data and return the FFT output data to the data-processing application for further processing.

[115] The exception manager **192** handles exception messages from the pipeline accelerator **14** (**FIG. 1**), and may detect and handle exceptions that result from the operation of the host processor **12**. The PLIC exception manager(s) **88** (**FIG. 3**) typically generate the exception messages that the exception manager **192** receives from the pipeline accelerator **14**.

[116] And, as discussed further below in conjunction with **FIGS. 11 – 14**, the configuration manager **194** downloads the firmware files **180** from the library **106** (**FIGS. 4** and **9**) into accelerator the firmware memory or memories **22** (**FIGS. 1 – 3**) during initialization of the peer-vector machine

10 (FIG. 1), and may also reconfigure the pipeline accelerator **14 (FIG. 1)** after the initialization in response to, e.g., a malfunction of the peer-vector machine. The configuration manager **194** may perform additional functions as described below in conjunction with **FIGS. 11 – 14**.

5 [117] The processing-unit applications **190, 192**, and **194** may communicate with each other directly as indicated by the dashed lines **196, 198**, and **200**, or may communicate with each other via the data-transfer objects **202**, which are described below. Furthermore, the processing-unit applications **190, 192**, and **194** communicate with the pipeline accelerator
10 **14 (FIG. 1)** via the data-transfer objects **202**.

[118] The message handler **34** executes the data-transfer objects **202**, a communication object **204**, and input and output reader objects **206** and **208**, and may also execute input- and output-queue objects **210** and **212**. The data-transfer objects **202** transfer data between the
15 communication object **204** and the processing-unit applications **190, 192**, and **194**, and may use the interface memory **18** as one or more data buffers to allow the processing-unit applications and the pipeline accelerator **14 (FIG. 1)** to operate independently. For example, the memory **18** allows the accelerator **14**, which is often faster than the data-processing application
20 **190**, to operate without "waiting" for the data-processing application. The communication object **204** transfers data between the data-transfer objects **202** and the pipeline bus **20**. The input- and output-reader objects **206** and **208** control the data-transfer objects **202** as they transfer data between the communication object **204** and the processing-unit applications **190, 192**,
25 and **194**. And, when executed, the input- and output-queue objects **210** and **212** cause the input- and output-reader objects **206** and **208** to synchronize this transfer of data according to a desired priority

[119] Furthermore, during initialization of the peer-vector machine **10 (FIG. 1)**, the message handler **34** instantiates and executes an object
30 factory **214**, which instantiates the data-transfer objects **202** from

configuration data stored in the message-configuration registry **42** (**FIG. 1**). The message handler **34** also instantiates the communication object **204**, the input- and output-reader objects **206** and **208**, and the input- and output-queue objects **210** and **212** from the configuration data stored in the message-configuration registry **42**. Consequently, one can design and modify the objects **202 – 212**, and thus their data-transfer parameters, by merely designing or modifying the configuration data stored in the registry **42**. This is typically less time consuming than designing or modifying each software object individually.

[120] The structure and operation of the processing unit **32** and the message handler **34** are further described in previously incorporated U.S. Patent Publication No. 2004/0181621.

[121] The operation of the exception manager **192** and the configuration manager **194** is further discussed below in conjunction with **FIGS. 11 – 14** according to an embodiment of the invention.

[122] **FIG. 11** is a block diagram of a circuit **220** that is designed for instantiation on the pipeline accelerator **14** (**FIG. 1**) according to an embodiment of the invention. The clock signals, power signals, and other signals are omitted from **FIG. 11** for clarity.

[123] During operation, the circuit **220** generates, in a pipelined fashion, a stream of output values y from streams of input values x and z , which are related by the following equation:

$$(1) \quad y = \sqrt{ax^4 \cos(z) + bz^3 \sin(x)}$$

where each x and z is a sixty-four bit floating-point number, each y is a sixty-four bit floating-point number, and a and b are respective sixty-four bit floating-point constant coefficients. Therefore, the circuit **220** is designed for instantiation on a pipeline accelerator **14** (**FIG. 1**) that supports a platform that specifies sixty-four-bit data transfers and busses.

[124] As initially designed, the circuit **220** includes eight hardwired pipelines **44**₁ – **44**₈ (pipelines **44**₅ and **44**₆ are the same) and eight hardware-interface layers **62**₁ – **62**₈ respectively instantiated on eight PLICs **60**₁ – **60**₈. The pipeline **44**₁ on the PLIC **60**₁ receives the stream of input values x and generates a stream of values $\sin(x)$. Similarly, the pipeline **44**₂ on the PLIC **60**₂ receives the stream of input values z and generates a stream of values bz^3 , the pipeline **44**₃ on the PLIC **60**₃ receives the stream x and generates a stream ax^4 , and the pipeline **44**₄ on the PLIC **60**₄ receives the stream z and generates a stream $\cos(z)$. Furthermore, the pipeline **44**₅ on the PLIC **60**₅ receives from the PLICs **60**₁ and **60**₂ the streams $\sin(x)$ and bz^3 and generates a stream of values $bz^3\sin(x)$, and the pipeline **44**₆ on the PLIC **60**₆ receives from the PLICs **60**₃ and **60**₄ the streams ax^4 and $\cos(z)$ and generates a stream $ax^4\cos(z)$. In addition, the pipeline **44**₇ on the PLIC **60**₇ receives from the PLICs **60**₅ and **60**₆ the streams $bz^3\sin(x)$ and $ax^4\cos(z)$ and generates a stream $bz^3\sin(x) + ax^4\cos(x)$. Finally, the pipeline **44**₈ on the PLIC **60**₈ receives from the PLIC **60**₇ the stream $bz^3\sin(x) + ax^4\cos(x)$ and generates a stream $y = \sqrt{ax^4\cos(z) + bz^3\sin(x)}$ per equation (1).

[125] FIG. 12 is a block diagram of the data paths between the PLICs **60**₁ – **60**₈ of FIG. 11 according to an embodiment of the invention, and is further described below.

[126] FIG. 13 is a block diagram of the circuit **220** modified for instantiation on seven PLICs **60** instead of eight PLICs (as shown in FIG. 11) according to an embodiment of the invention, and is further described below.

[127] FIG. 14 is a block diagram of the data paths between the PLICs **60**₁ and **60**₃ – **60**₈ of FIG. 11 and a software-application thread that effectively replaces the pipeline **44**₂ of FIG. 11 according to an embodiment of the invention, and is further described below.

**Operation of the Configuration Manager 194 (FIG. 10) During
Initialization Of The Peer-Vector Machine 10 (FIG. 1)**

[128] The operation of the configuration manager **194** during the initialization of the peer-vector machine **10 (FIG. 1)** is discussed in
5 conjunction with **FIGS. 10 – 14** according to embodiments of the invention. Although a number of detailed operational examples are provided below, the following is a general overview of the configuration manager **194** and some of the advantages that it may provide.

[129] The configuration manager **194** initializes the peer-vector
10 machine **10 (FIG. 1)** when the machine is “turned on,” restarted, or is otherwise reset.

[130] At the beginning of the initialization, the configuration manager **194** determines the desired configuration of the pipeline accelerator **14 (FIG. 1)** from the configuration data **100 (FIG. 4)** within the accelerator/host-processor-configuration registry **40 (FIGS. 1 and 4)**, and also determines
15 the physical composition (e.g., the number of pipeline units **50 (FIGS. 2 – 3)** and the platform(s) that they support) of the pipeline accelerator.

[131] Therefore, because the configuration manager **194** configures the pipeline accelerator **14 (FIG. 1)** in response to the configuration data
20 **100 (FIG. 4)**, one can typically change the accelerator configuration merely by “turning off” the peer-vector machine **10 (FIG. 1)**, changing the configuration data, and then restarting the machine.

[132] Furthermore, by determining the composition of the pipeline accelerator **14 (FIG. 1)** at the beginning of each initialization, the
25 configuration manager **194** can detect changes to the accelerator (e.g., the removal or addition of a pipeline unit **50 (FIGS. 2– 3)**, and can often “fit” the by the configuration data **100 (FIG. 4)** into an altered accelerator. That is, the configuration manager **194** can often detect a physical change to the accelerator **14** and modify the specified circuit instantiation(s) accordingly

so that the circuit(s) can fit onto the modified accelerator and process data as desired despite the change.

Example 1

[133] Referring to **FIGS. 10 – 12**, in this example, the configuration data **100** (**FIG. 4**) points to a circuit-definition file **170** (**FIGS. 4** and **8**) that defines the circuit **220** of **FIG. 11**, and instructs the configuration manager **194** to instantiate the circuit **220** on the pipeline accelerator **14** (**FIG. 1**) according to this circuit-definition file.

[134] At the beginning of the initialization of the peer-vector machine **10** (**FIG. 1**), the configuration manager **194** reads the configuration data **100**, determines from the configuration data the desired configuration of the pipeline accelerator **14** (**FIG. 1**), and also determines the physical composition of the pipeline accelerator. Regarding the former determination, the configuration manager **194** first determines that it is to read the circuit-definition file **170** pointed to by the configuration data **100**. Next, the configuration manager **194** reads the file **170**, and determines that the manager is to instantiate on each of the eight PLICs **60₁ – 60₈** a respective pipeline **44₁ – 44₈** (pipelines **44₅** and **44₆** are the same) and hardware-interface layer **62₁ – 62₈**. Regarding the determination of the composition of the pipeline accelerator **14**, the pipeline bus **20** (**FIG. 1**) may include slots for receiving pipeline units **50** (**FIGS. 2 – 3**), and the configuration manager **194** may, for each slot, read a conventional indicator associated with the slot, or use another technique, for determining whether or not a pipeline unit is inserted into the slot.

[135] Next, the configuration manager **194** determines whether the configuration indicated by the configuration data **100** (**FIG. 4**) is compatible with the physical composition of the pipeline accelerator **14** (**FIG. 1**). Specifically, in this example, the configuration manager **194** determines whether the accelerator **14** includes eight pipeline units **50** each having a respective one of the PLICs **60₁ – 60₈** on which the configuration manager

can instantiate the pipeline units **44₁ – 44₈** and the hardware-interface layers **62₁ – 62₈**.

[136] In this example, the configuration manager **194** determines that the desired configuration of the pipeline accelerator **14** (**FIG. 1**) is

5 compatible with the physical composition of the accelerator.

[137] Consequently, the configuration manager **194** next determines whether the pipeline accelerator **14** (**FIG. 1**) supports the platform(s) that circuit-definition file **170** specifies as being compatible with the circuit **220**.

More specifically, the configuration manager **194** reads from the file **170** the
10 specified platform(s), and reads from the platform-identifier memory **54** (**FIGS. 2 – 3**) on each pipeline unit **50** (**FIGS. 2 – 3**) the identity/identities of the platform(s) that the pipeline units support. Then, the configuration manager **194** compares the specified platform(s) from the file **170** to the identified platform(s) from the memories **54**. If at least one platform from
15 the file **170** matches at least one platform from the memories **54**, then the configuration manager **194** determines that the platform(s) supported by the pipeline accelerator **14** is/are compatible with the platform(s) specified by the file **170**. In this example, the file **170** indicates that the circuit **220** is compatible with platform 1 (**FIG. 6**), and the platform-identifier memory **54**
20 on each pipeline unit **50** indicates that the respective pipeline unit is compatible with this platform; consequently, the configuration manager **194** determines that the pipeline accelerator **14** is compatible with the platform (i.e., platform 1) specified by the circuit-definition file **170**.

[138] In this example, the configuration manager **194** determines that
25 the pipeline accelerator **14** (**FIG. 1**) supports the platform(s) that the circuit-definition file **170** (**FIG. 8**) specifies.

[139] Therefore, the configuration manager **194** next determines whether the firmware library **108** (**FIGS. 4 and 9**) includes firmware files **180** that, when downloaded by the PLICs **60₁ – 60₈**, will respectively instantiate
30 on these PLICs the pipelines **44₁ – 44₈** and the hardware-interface layers

62₁ – 62₈. The configuration manager **194** makes this determination by reading the firmware descriptions **182** in the library **108**. For example, if the description **182₁** indicates that the corresponding firmware file **180₁** will instantiate the pipeline **44₁** within a hardware-interface layer (*i.e.*, the hardware-interface layer **62₁**) that is compatible with platform 1 then the configuration manager **194** matches the firmware file **180₁** to the PLIC **60₁** in the circuit **220**.

[140] In this example, the configuration manager **194** determines that the library **108** (**FIGS. 4 and 8**) contains firmware files **180₁ – 180₇** for each of the PLICs **60₁ – 60₈** — the firmware file **180₅** is for both the PLICs **60₅** and **60₆** — because the pipelines **44₅ – 44₆** are the same.

[141] Consequently, the configuration manager **194** next downloads these firmware files **180₁ – 180₇** (**FIG. 8**) to the PLICs **60₁ – 60₈** (**FIG. 11**) via the pipeline bus **20**. Techniques for downloading these firmware files are described in previously incorporated U.S. Patent Publication No. 2004/0170070.

[142] Then, the configuration manager **194** determines the topology that the circuit-definition file **170** (**FIG. 7**) specifies for interconnecting the PLICs **60₁ – 60₈** of the circuit **220** (**FIG. 11**).

[143] In this example, the circuit-description file **170** (**FIG. 7**) specifies that the PLICs **60₁ – 60₈** (**FIG. 11**) are to be interconnected via the host processor **12** (**FIG. 1**) as shown **FIG. 12**.

[144] Therefore, referring to **FIG. 12**, the configuration manager **194** instantiates in the interface memory **18** buffers **230₁ – 230₁₅**, and instantiates in the message handler **34** data-transfer objects **202₁ – 202₂₃**.

[145] Referring to **FIG. 11**, the PLIC **60₁** needs a path on which to provide the stream of values $\sin(x)$ to the corresponding input pin of the PLIC **60₅**. The configuration manager **194** forms this path by instantiating in the interface memory **18** the buffers **230₁** and **230₂**, and by instantiating in

the message handler **34** the data-transfer objects **202₁**, **202₂**, and **202₃**. In operation, the PLIC **60₁** provides the stream of values $\sin(x)$ to the data-transfer object **202₁** via the pipeline bus **20** and communication object **204**, and the data-transfer object **202₁** sequentially loads these values into the buffer **230₁**. Then, the data-transfer object **202₂** sequentially transfers the values $\sin(x)$ from the buffer **230₁** to the buffer **230₂** in first-in-first-out fashion, and the data-transfer object **202₃** transfers the values $\sin(x)$ from the buffer **230₂** in first-in-first-out fashion to the corresponding input pin of the PLIC **60₅** via the communication object **204** and the pipeline bus **20**.

10 The configuration manager **194** forms the remaining paths interconnecting the PLICs in a similar manner. Therefore, in operation the PLIC **60₂** transfers the values bz^3 to the corresponding input pin of the PLIC **60₅** via the data-transfer objects **202₄ – 202₆** and the buffers **230₃ – 230₄**, the PLIC **60₃** transfers the values ax^4 to the corresponding input pin of the PLIC **60₆** via the data-transfer objects **202₇ – 202₉** and the buffers **230₅ – 230₆**, and

15 so on. Finally, the PLIC **60₈** provides the values $y = \sqrt{ax^4 \cos(z) + bz^3 \sin(x)}$ to the data-processing application **190** via the data-transfer objects **202₂₂** and **202₂₃** and the buffer **230₁₅**. Furthermore, the PLICs **60₁ – 60₄** may receive the values x and z via the raw-data input port **24**, or from the data-

20 processing application **190** via respective buffers **230** and data-objects **202** (omitted from **FIG. 12** for brevity) that the configuration manager **194** instantiates in response to the circuit-definition file **170**. For example, the data-processing application **190** may provide the values x to a first data-transfer object **202** (not shown), which loads the values x into a buffer

25 **230** (not shown). Then, a second data-transfer object **202** (not shown) unloads the values x from the buffer **230** and provides these values to the corresponding input pins of the PLICs **60₁** and **60₃** via the communication object **204** and the pipeline bus **20**.

[146] After instantiating the data-transfer objects **202₁ – 202₂₃**, and

30 the buffers **230₁ – 230₁₅** (and possibly the data-transfer objects and buffers

described in the preceding paragraph), the configuration manager **194** sends to the configuration managers **88** (**FIG. 3**) on each of the PLICs **60₁ – 60₈** any soft-configuration data specified by the circuit-definition file **170**. For example, the configuration manager **194** may send to the configuration managers **88** on the PLICs **60₂** and **60₃** soft-configuration data that sets the values of the constants *a* and *b*. Or, the configuration manager **194** may send to the configuration managers **88** on the PLICs **60₁** and **60₄** soft-configuration data that causes the respective exception managers **86** on these PLICs to indicate exceptions for values of $\sin(x)$ and $\cos(x)$ outside of the ranges $-1 \leq \sin(x) \leq 1$ and $-1 \leq \cos(x) \leq 1$, respectively. In one embodiment, the configuration manager **194** sends this soft-configuration data to the PLICs **60₁ – 60₈** via one or more data-transfer objects **202** that the configuration manager has instantiated for this purpose.

[147] After soft configuring the PLICs **60₁ – 60₈** and configuring any remaining portions of the pipeline accelerator **14** (**FIG. 1**), the interface memory **18**, and the message handler **34**, the configuration manager **194** exits the initialization mode and relinquishes control of the peer-vector machine **10** (**FIG. 1**) back to the host processor **12**, which enters an operational mode where the PLICs **60₁ – 60₈** cooperate as described above to generate a stream of output values $y = \sqrt{ax^4 \cos(z) + bz^3 \sin(x)}$ in a pipelined fashion.

Example 2

[148] Referring to **FIGS. 10 – 13**, this example is similar to Example 1, except that the configuration manager **194** determines that the pipeline accelerator **14** (**FIG. 1**) includes fewer than eight PLICs **60**, and thus arranges the circuit **220** to “fit” onto the available PLICs.

[149] More specifically, the configuration manager **194** determines that the pipeline accelerator **14** includes only seven PLICs **60₁ – 60₅** and **60₇ – 60₈**.

[150] The configuration manager **194** sends this information to a circuit-design tool such as the circuit-design tool described in previously incorporated U.S. Patent Application Ser. No. _____ (Attorney Docket No. 1934-023-03). The tool may be executed by the host processor **12**
5 (FIG. 1), and the configuration manager **194** may communicate with the tool via one or more data-transfer objects **202**.

[151] In a first embodiment, the circuit-design tool determines that the circuit **220** cannot fit onto the pipeline accelerator **14** (FIG. 1), and notifies the configuration manager **194**, which generates an appropriate
10 error message. The host processor **12** (FIG. 1) may display this message via a display or by another conventional technique. In response to this message, an operator (not shown) can install into the peer-vector machine **10** (FIG. 1) an additional pipeline unit **50** (FIG. 2) that includes the PLIC **60₆** so that the configuration manager **194** can then instantiate the circuit **220**
15 on the pipeline accelerator **14** as described above in Example 1.

[152] Referring to FIGS. 6 and 10 – 13, in a second embodiment, the circuit-design tool (not shown) accesses the library **102** and discovers a template **134₉** for a dual-multiplication pipeline **44₉** (two multipliers in a single pipeline), and determines from the corresponding hardwired-pipeline-
20 template description **156₉** that this pipeline (along with a corresponding hardware-interface layer **62₉**) can fit into the PLIC **60₅** and can give the circuit **220** the desired operating parameters (as included in the circuit-definition file **170** that defines the circuit **220**). Then, using this
dual-multiplication pipeline **44₉**, the tool redesigns the circuit **220** as shown
25 in FIG. 13 for instantiation on seven PLICS **60₁ – 60₅** and **60₇ – 60₈**, generates a circuit-definition file **170** corresponding to the redesigned circuit **220**, and stores this circuit-definition file in the library **106** (FIGS. 4 and 8). The configuration manager **194** then instantiates the redesigned circuit **220** in a manner similar to that discussed above in conjunction with Example 1.
30 If, however, the firmware library **108** includes no firmware file **180** for

instantiating the dual-multiplier pipeline **44₉** on the PLIC **60₅**, then the circuit design tool or the configuration manager **194** may notify an operator (not shown), who manually generates this firmware file and loads it into the firmware library. Alternatively, the circuit-design tool or the configuration manager **194** may cause a PLIC synthesizing and routing tool (not shown) to generate this firmware file from the appropriate templates in the accelerator-template library **102** (**FIGS. 4** and **6**). Once this firmware file is generated and stored in the library **108**, the configuration manager **194** proceeds to instantiate the redesigned circuit **220** of **FIG. 13** in a manner similar to that discussed above in conjunction with Example 1.

[153] Alternate embodiments of Example 2 are contemplated. For example, although Example 2 describes placing two multipliers on a single PLIC **60₅**, the configuration manager **194** and/or the circuit-design tool (not shown) may fit the functions of multiple ones of the other pipelines **44₁ – 44₈** of the circuit **220** on a single PLIC, including placing on a single PLIC a single pipeline that generates y in equation (2). Moreover, the circuit-design tool (not shown) may instantiate multiple interconnected ones of the pipelines **44₁ – 44₈** (**FIG. 11**) on a single PLIC instead of searching for existing pipelines that each perform multiple ones of the functions performed by the pipelines **44₁ – 44₈**.

Example 3

[154] Referring to **FIGS. 10 – 14**, this example is similar to Example 2, except that the configuration manager **194** effectively replaces a hardwired pipeline **44** with a software object **160** (**FIG. 7**) from the software-object library **104** (**FIGS. 4** and **7**).

[155] More specifically, the configuration manager **194** determines that the pipeline accelerator **14** (**FIG. 1**) includes only seven PLICs **60₁ – 60₆** and **60₈**.

[156] The configuration manager **194** next reads the software-object descriptions **162** (FIG. 7) and determines that the software object **160₁** can sum two values such as $bz^3\sin(x)$ and $ax^4\cos(z)$.

[157] Consequently, referring to FIGS. 11 and 14, the configuration manager **194** instantiates the software object **160₁** (FIG. 7) as part of a data-processing application thread **240** that, after the instantiation of the remaining portions of the circuit **220** on the pipeline accelerator **44** (FIG. 1), receives $bz^3\sin(x)$ and $ax^4\cos(z)$ from the PLICs **60₅** and **60₆**, respectively, sums corresponding values from these two streams, and then provides $bz^3\sin(x) + ax^4\cos(z)$ to the PLIC **60₈**. More specifically, the thread **240** receives $bz^3\sin(x)$ from the PLIC **60₅** via the pipeline **20**, communication object **204**, data-transfer object **202₂₄**, buffer **230₁₅**, and data-transfer object **202₂₅**. Similarly, the thread **240** receives $ax^4\cos(z)$ from the PLIC **60₆** via the pipeline **20**, communication object **204**, data-transfer object **202₂₆**, buffer **230₁₆**, and data-transfer object **202₂₇**. And the thread provides $bz^3\sin(x) + ax^4\cos(z)$ to the PLIC **60₈** via the data-transfer object **202₂₈**, buffer **230₁₇**, data-transfer object **202₂₉**, communication object **204**, and pipeline **20**. The configuration manager **194** instantiates these data-transfer objects and buffers as described above in conjunction with Example 1. Furthermore, the operation and instantiation of application threads such as the thread **240** are described in previously incorporated U.S. Patent Publication No. 2004/0181621.

[158] Next, the configuration manager **194** proceeds to instantiate the remaining portions of the circuit **220** on the pipeline accelerator **14** (FIG. 1) in a manner similar to that discussed above in conjunction with Example 1.

[159] Although Example 3 describes replacing a single pipeline **44₆** with a data-processing application thread **240** that executes a single corresponding software object **160** (FIG. 7), the configuration manager **194** may replace any number of the pipelines **44₁ – 44₈** in the circuit **220** (FIG.

11) with one or more threads that execute corresponding software objects. Moreover, the configuration manager **194** may combine the concepts described in conjunction with Examples 2 and 3 by fitting multiple pipelines **44** or multiple pipeline functions on each of one or more PLICs, and
5 replacing other pipelines **44** with one or more data-processing application threads that execute corresponding software objects **160**.

Example 4

[160] Referring to **FIGS. 10 – 12** and **14**, this example is similar to Example 1, except that the configuration manager **194** determines that the
10 pipeline accelerator **14** (**FIG. 1**) does not support the platform(s) that circuit-definition file **170** (**FIG. 8**) specifies as being compatible with the circuit **220**.

[161] In a first embodiment, the configuration manager **194** generates an error message, and, in response, an operator (not shown)
15 replaces the pipeline units **50** (**FIG. 2**) that do not support the specified platform(s) with pipeline units that do support the specified platform(s).

[162] In a second embodiment, the configuration manager **194** instantiates a circuit that performs the same function as the circuit **220** (i.e., generates y in equation (1)) by downloading into the available PLICs
20 firmware files **180** (**FIG. 9**) that instantiate the hardwired pipelines **44₁ – 44₈** with respective hardware-interface layers **62** that are compatible with the platform(s) supported by the pipeline accelerator **14** (**FIG. 1**). If the library **108** (**FIGS. 4** and **8**) does not contain such firmware files **180**, then the configuration manager **194** and/or a circuit-design tool such as that
25 described in previously incorporated U.S. Patent Application Ser. No. _____
_____ (Attorney Docket No. 1934-023-03) may generate these firmware files from the templates in the library **102** (**FIGS. 4** and **6**) as discussed above in conjunction with Example 2.

[163] In a third embodiment, the configuration manager **194** instantiates the function of the circuit **220** (i.e., generates y in equation (1)) in one or more data-processing application threads **240** as discussed above in conjunction with Example 3.

- 5 [164] In a fourth embodiment, the configuration manager **194** instantiates a portion of the circuit **220** on the pipeline accelerator **14** per the above described second embodiment of Example 4, and effectively instantiates the remaining portion of the circuit **220** in one or more data-processing application threads per the preceding paragraph.

10 **Example 5**

- [165] Referring to **FIGS. 10 – 12**, and **14**, this example is similar to Example 1, except that the configuration manager **194** determines that the library **108** (**FIGS. 4** and **8**) lacks at least one of the firmware files **180₁ – 180₇** for the PLICs **60₁ – 60₈** (the firmware file **180₅** corresponds to both the
15 PLICs **60₅** and **60₆**).

- [166] In a first embodiment, the configuration manager **194** generates an error message, and, in response, an operator loads the missing firmware file(s) **180** (**FIG. 8**) into the library **108** (**FIGS. 4** and **8**) so that the configuration manager can proceed with instantiating the circuit **220**
20 on the PLICs **60₁ – 60₈** as discussed above in conjunction with Example 1.

- [167] In a second embodiment, the configuration manager **194** and/or a circuit-design tool such as that described in previously incorporated U.S. Patent Application Ser. No. _____ (Attorney Docket No. 1934-023-03) generates these firmware files from the templates (**FIG. 6**) in the library **102** (**FIGS. 4** and **6**) as discussed above in conjunction with
25 Example 2. Then, the configuration manager **194** loads these generated firmware files **180** into the library **108**, and instantiates the circuit **220** on the PLICs **60₁ – 60₈** as discussed above in conjunction with Example 1.

[168] In a third embodiment, the configuration manager **194** instantiates the function of a pipeline **44** corresponding to a missing firmware file **180** in a data-processing application thread **240** as discussed above in conjunction with Example 3.

- 5 [169] In a fourth embodiment, the configuration manager **194** instantiates on the pipeline accelerator **14** (FIG. 1) a portion of the circuit **220** per the above-described second embodiment of Example 5, and effectively instantiates the remaining portion of the circuit **220** in one or more data-processing application threads **240** per the preceding paragraph.

10 **Example 6**

- [170] Referring to FIGS. 10 – 11, this example is similar to Example 1, except that the circuit-definition file **170** (FIG. 8) that defines the circuit **220** specifies that the PLICs **60₇ – 60₈** are to be “directly” interconnected via the pipeline bus **20** (FIG. 1). That is, the PLIC **60₇** provides the stream of values $\sin(x)$ to the PLIC **60₅** without going through the message handler **34** and memory **18** as shown in FIG. 12.

- [171] In a first embodiment, the corresponding firmware files **180₁ – 180₇** (file **180₅** is used twice) instantiate the communication interfaces **80** (FIG. 3) of the PLICs **60₇ – 60₈** to generate and send message objects (not shown) that identify the recipient PLIC and to recognize and receive messages from specified sender PLICs. Such message objects are described in previously incorporated U.S. Patent Publication No. 2004/0181621. In summary, these message objects each include an address header that identifies the destination PLIC or PLICs. For example, the communication interface **80** (FIG. 3) of the PLIC **60₇** generates message objects that carry values $\sin(x)$ to the PLIC **60₅**. These message objects each include an address header that includes the address of the PLIC **60₅**. Therefore, when the communication interface **80** of the PLIC **60₅** detects on the pipeline bus **20** (FIG. 1) a message object having this address, the interface uploads this message object from the bus. The

remaining PLICs **60₂ – 60₈** receive and generate message objects in a similar manner.

[172] In a second embodiment, the configuration manager **194** soft configures the communication interfaces **80 (FIG. 3)** of the PLICs **60₁ – 60₈** to receive and generate message objects per the preceding paragraph by sending appropriate soft-configuration data to the configuration managers **88 (FIG. 3)** of the PLICs as discussed above in conjunction with Example 1.

[173] Referring to **FIGS. 4 -14**, other embodiments of the peer vector machine **10 (FIG. 1)** are contemplated. For example, instead of pointing to a circuit-definition file **170** in the circuit-definition library **106**, the configuration data **100** may include meta-data that describes an algorithm, such as the algorithm represented by equation (1), and the configuration manager **194** may cause the peer vector machine **10** to implement the algorithm based on this meta-data. More specifically, the configuration manager **194** may first determine the attributes of the peer vector machine **10** as previously described. Next, based on the meta-data and the determined attributes of the peer vector machine **10**, the configuration manager **194** may define an implementation of the algorithm that is compatible with the platform(s) supported by, and the components present within, the peer vector machine. The configuration manager **194** may define the implementation using one or more templates from the library **102**, one or more software objects **160** from the library **104**, one or more circuit-definition files from the library **106**, and one or more firmware files **180** from the library **108**, or using any combination of these items. Then, the configuration manager **194** may instantiate the implementation on the peer vector machine **10** using any technique described above, any other technique(s), or any combination of these described/other techniques. Of course the configuration data **100** may include both meta-data that describes an algorithm and a pointer to a circuit-definition file **170** that defines a circuit for implementing the algorithm. If for some reason the

circuit defined by the file **170** is incompatible with the peer vector machine **10**, then the configuration manager **194** may define an implementation of the algorithm per above. Moreover, one may write such meta-data manually, or use a tool, such as that described in previously incorporated
5 U.S. Patent App. Ser. No. (Attorney Docket Nos. 1934-23-3 and 1934-35-3), to generate the meta-data.

Reconfiguration of the Peer-Vector Machine 10 of FIG. 1 by the Configuration Manager 194 While The Peer-Vector Machine Is Operating (Dynamic Reconfiguration)

10 [174] Dynamic reconfiguration of the peer-vector machine **10** (**FIG. 1**) by the configuration manager **194** (**FIG. 10**) is discussed below in conjunction with **FIGS. 10 – 12** and **14 – 16** according to embodiments of the invention. Although a number of detailed examples are provided below, the following is a general overview of dynamic reconfiguration and some of
15 the advantages that it provides.

[175] Conventional fault-tolerant computing machines (not shown) often have built-in redundancy such that if one portion of the machine fails during operation, another, redundant, portion can take over for the failed part. For example, if a processor fails, then a redundant processor can take
20 over for the failed processor. Typically, if one wants to add redundancy for a component of the machine, then he adds to the machine a like redundant component. For example, if one wants to add redundancy to a bank of processors, then he typically adds to the machine at least one redundant processor. The same is true for other components such as hard drives.

25 [176] The configuration manager **194** can render the peer-vector machine **10** (**FIG. 1**) fault tolerant in a manner that is often more flexible and less costly than a conventional redundancy scheme. For example, as discussed below, the configuration manager **194** may transfer a function previously performed by a failed pipeline unit **50** (**FIG. 2**) of the pipeline
30 accelerator **14** (**FIG. 1**) to the host processor **12** (**FIG. 1**), and vice versa.

That is, the host processor **12** may provide redundancy to the accelerator **14**, and vice versa. Consequently, instead of adding redundant processing units to the host processor **12**, it may be less expensive and less complex from a design perspective to add extra pipeline units **50** to the accelerator **14**, where the configuration manager **194** can use these extra units to provide redundancy to both the host processor **12** and the accelerator. Or, instead of adding extra pipeline units **50** to the accelerator **14**, it may be less expensive and less complex from a design perspective to add extra processing units **32** to the host processor **12**, where the configuration manager **194** can use these extra processing units to provide redundancy to both the host processor and the accelerator. Of course the peer-vector machine **10** may include both extra processing units **32**, and pipeline units **50** and may also include extras of other components of the host-processor **12** and the accelerator **14**.

15 Example 7

[177] The PLIC **60_i** (**FIG. 11**), or another portion of the pipeline unit **50_i**, on which the PLIC **60_i** is disposed, experiences a "soft" failure while the peer-vector machine **10** (**FIG. 1**) is operating, and the circuit **220** is executing equation (1). Examples of a soft failure include, e.g., corrupted configuration firmware or soft-configuration data stored in the PLIC **60_i**, a buffer overflow, and a value $\sin(x)$ that is generated by the pipeline **44_i** on the PLIC **60_i** but that is out of the predetermined range $-1 \leq \sin(x) \leq 1$.

[178] First, the accelerator-exception manager **192** detects the failure of the PLIC **60_i**.

25 [179] In one embodiment, the exception manager **192** detects the failure in response to an exception received from the exception manager **86** on board the PLIC **60_i**. For example, because $-1 \leq \sin(x) \leq 1$, then the exception manager **86** may be programmed to generate an exception if a value generated by the pipeline **44_i** is less than -1 or greater than 1. Or,

the exception manager **86** may be programmed to send an exception if an input buffer for the value x on the data memory **58** overflows.

[180] In a second embodiment, the exception manager **192** detects the failure in response to an improper value of data provided to or

5 generated by the pipeline **44₁** on the PLIC **60₁**. For example, the exception manager **192** may periodically analyze the stream of values x provided to the PLIC **60₁**, or the stream of values $\sin(x)$ provided by the PLIC **60₁**, and detect a failure of the PLIC **60₁** if any of the analyzed values are less than -1 or greater than 1.

10 [181] In a third embodiment, the exception manager **192** detects the failure in response to the PLIC **60₁** failing to provide the stream of values $\sin(x)$. For example, per the previous paragraph, the exception manager **192** may periodically analyze the stream of values $\sin(x)$ provided by the PLIC **60₁**, and detect a failure of the PLIC **60₁** if the PLIC **60₁** stops
15 generating $\sin(x)$ despite continuing to receive the stream of input values x .

[182] Next, the exception manager **192** notifies the configuration manager **194** that the PLIC **60₁** has experienced a soft failure.

[183] In response to this notification, the configuration manager **194** first halts the processing of data by the PLICs **60₁ – 60₈** and any related
20 data-processing applications **190** that the processor unit **32** is executing. Examples of a related data-processing application **190** include an application that generates the values x or z or that receives and processes the values y .

[184] Next, if the configuration manager **194** previously loaded
25 soft-configuration data into the PLIC **60₁** during initialization of the peer-vector machine **10** (FIG. 1), then the configuration manager reloads this data into the PLIC **60₁** and restarts the processing of data by the PLICs **60₁ – 60₈** and any related data-processing applications **190** that the processing unit **32** is executing.

[185] If the exception manager **192** detects no failure of the PLIC **60₁** after the restart, then the configuration manager **194** allows the PLICs **60₁ – 60₈** and any related data-processing applications **190** to continue processing data.

5 [186] But if the configuration manager **194** did not load soft-configuration data into the PLIC **60₁** during initialization of the peer-vector machine **10**, or if the exception manager **192** detects a failure of the PLIC **60₁** after the restart, then the configuration manager again halts the processing of data by the PLICs **60₁ – 60₈** and any related
10 data-processing applications **190**.

[187] Next, the configuration manager **194** causes the PLIC **60₁** to re-download the firmware file **180** (**FIG. 9**) that the PLIC **60₁** downloaded during initialization of the peer-vector machine **10** (**FIG. 1**), and restarts the PLICs **60₁ – 60₈** and any related data-processing applications **190** for a
15 second time.

[188] If the exception manager **192** detects no failure of the PLIC **60₁** after the restart, then the configuration manager **194** allows the PLICs **60₁ – 60₈** and any related data-processing applications **190** to continue processing data.

20 [189] But if the exception manager **192** detects a failure of the PLIC **60₁** after the second restart, then the configuration manager **194** again halts the processing of data by the PLICs **60₁ – 60₈** and any related data-processing applications **190**.

[190] Then, the configuration manager **194** determines whether the
25 pipeline accelerator **14** (**FIG. 1**) includes an extra PLIC **60** that is the same as or is similar to the PLIC **60₁**. The extra PLIC may be a PLIC that is reserved to replace a failed PLIC, or may merely be a PLIC that is unused. Also, the extra PLIC may be on an extra pipeline unit **50**, or on a pipeline unit **50** that includes other, no-extra PLICs.

[191] If the pipeline accelerator **14** (**FIG. 1**) does include an extra PLIC, then the configuration manager **194** causes the extra PLIC to download the same firmware file **180** (**FIG. 9**) previously downloaded by the PLIC **60₁** during initialization of the peer-vector machine **10** (**FIG. 1**) and
5 prior to the second restart.

[192] Next, the configuration manager **194** restarts the PLICs **60₂ – 60₈**, the extra PLIC, and any related data-processing applications **190** such that the extra PLIC takes the place of the failed PLIC **60₁** in the circuit **220**.

[193] If the exception manager **192** detects no failure of the extra
10 PLIC after the third restart, then the configuration manager **194** allows the PLICs **60₂ – 60₈**, the extra PLIC, and any related data-processing applications **190** to continue processing data.

[194] But if the pipeline accelerator **14** (**FIG. 1**) includes no extra PLIC, or if the exception manager **192** detects a failure of the extra PLIC
15 after the third restart, then the configuration manager **194** halts for a fourth time the processing of data by the PLICs **60₁ – 60₈** and any related data-processing applications **190** if the data processing is not already halted.

[195] Then, if the pipeline accelerator **14** (**FIG. 1**) includes another
20 extra PLIC, then the configuration manager **194** may replace the failed PLIC **60₁** with this other extra PLIC, and restart the data processing as discussed above.

[196] But if the pipeline accelerator **14** (**FIG. 1**) contains no other
extra PLICs (or if these extra PLICs fail), then the configuration manager
25 **194** determines whether the circuit **220** can “fit” into the remaining PLICs **60₂ – 60₈** in a manner similar to that discussed above in conjunction with Example 2.

[197] If the circuit **220** can “fit” into the remaining PLICs **60₂ – 60₈**, then the configuration manager **194** reinstantiates the circuit **220** on these

remaining PLICs in a manner similar to that discussed above in conjunction with Example 2, and restarts the PLICs **60₂ – 60₈** and any related data-processing applications **190**.

[198] If the exception manager **192** detects no failure of the
5 reinstantiated circuit **220** after the restart, then the configuration manager **194** allows the PLICs **60₂ – 60₈** and any related data-processing applications **190** to continue processing data.

[199] But if the circuit **220** cannot fit into the PLICs **60₂ – 60₈**, or if
exception manager **192** detects a failure of the reinstantiated circuit **220**
10 after the restart, then the configuration manager **194** halts the processing of data by the PLICs **60₂ – 60₈** and any corresponding data-processing applications **190** if the data-processing is not already halted.

[200] Next, the configuration manager **194** reads the software-object
descriptions **192** (**FIG. 7**) to determine whether the library **104** (**FIGS. 4** and
15 **7**) includes a software object **160** (**FIG. 7**) that can generate *sin(x)*.

[201] If the library **104** (**FIGS. 4** and **7**) includes such a *sin(x)*
software object **160** (**FIG. 7**), then the configuration manager **194**
instantiates on the processing unit **32** a data-processor application thread
that executes the object **160** for generating *sin(x)* in a manner similar to that
20 discussed above in conjunction with Example 3 and **FIG. 14**, and restarts the data processing.

[202] If the exception manager **192** detects no failure of the circuit
220 (includes the application thread executing the *sin(x)* software object
160) after the restart, then the configuration manager **194** allows the PLICs
25 **60₂ – 60₈**, the *sin(x)* application thread that executes the *sin(x)* software object **160**, and any related data-processing applications to continue processing data.

[203] But if the library **104** (**FIGS. 4** and **7**) includes no *sin(x)*
software object **160** (**FIG. 4**), then the configuration manager **194** generates

an error message, in response to which an operator (not shown) may take corrective action such as replacing the PLIC **60₁**, or replacing the pipeline unit **50** on which the defective PLIC **60₁** is disposed.

[204] Still referring to **FIGS. 3, 10, and 11**, alternate embodiments of Example 7 are contemplated. For example, the configuration manager **194** may omit any number of the above-described steps, and perform the non-omitted steps in any order. An example, in response to a failure of the PLIC **60₁**, the configuration manager **194** may generate an application thread that executes a *sin(x)* software object **160** (**FIG. 7**) without first trying to reconfigure the PLIC **60₁**, to re-download the respective firmware file **180** (**FIG. 9**) to the PLIC **60₁**, to replace the PLIC **60₁** with an extra PLIC, or to "fit" the circuit **220** on the remaining PLICs **60₂ – 60₈**. Furthermore, the exception manager **190** may be omitted, and the configuration manager **194** may directly detect the failure of one or more PLICs **60₁ – 60₈**. Moreover, although described as halting the PLICs **60₁ – 60₈** and related data-processing applications **190** in response to a failure of one of the PLICs **60₁ – 60₈**, the configuration manager **194** may halt other portions of the peer-vector machine **10** as well, including halting the entire peer-vector machine.

20 Example 8

[205] Referring to **FIGS. 3 and 10 – 11**, in this example, a data-processing application **190** is generating y of equation (1) and experiences a failure while the peer-vector machine **10** (**FIG. 1**) is operating. Examples of such failure include, e.g., a mechanical failure of one or more processors that compose the processing unit **32**, or the inability of the data-processing application **190** to process data at or above a specified speed.

[206] First, the exception manager **192** detects the failure of the data-processing application **190**.

[207] In a first embodiment, the exception manager **192** detects the failure in response to an improper value of *x* or *z* being provided to the data-processing application **190**, or in response to an improper value of *y* being generated by the application. For example, the exception manager **192**
5 may periodically analyze the respective streams of values *x* and *z* provided to the data-processing application **190**, or the stream of values *y* generated by the data-processing application, and detect a failure of the data-processing application if, e.g., the analyzed values are outside of a predetermined range or the data-processing application stops generating
10 output values *y* despite continuing to receive the values *x* and *z*.

[208] In a second embodiment, the exception manager **192** detects the failure in response to the frequency at which the data-processing application **190** generates the values *y* being below a predetermined frequency.

15 [209] Next, the exception manager **192** notifies the configuration manager **194** that the data-processing application **190** has failed.

[210] In response to this notification, the configuration manager **194** first halts the processing of data by the data-processing application **190** and any related PLICs **60** (**FIG. 3**) of the pipeline accelerator **14** (**FIG. 1**).
20 Examples of a related PLIC include a PLIC that generates the input values *x* or *z* for the data-processing application **190** or that receive the values *y* from the application.

[211] Next, if the failure is due to a mechanical failure of a portion of the processing unit **32**, then the configuration manager **194** determines
25 whether the data-processing application **190** can be loaded onto and run by another portion of the processing unit such as an extra processor.

[212] If the data-processing application **190** can be loaded onto and run by another portion of the processing unit **32**, then the configuration

manager **194** loads the data-processing application onto the other portion of the processing unit **32**, and restarts the application and any related PLICs.

[213] If the exception manager **192** detects no failure of the data-processing application **190** after the restart, then the configuration manager **194** allows the application and any related PLICs to continue processing data.

[214] But if the configuration manager **194** cannot load and run the data-processing application **190** on another portion of the processing unit **32**, or if the exception manager **192** detects a failure of the application after the restart, then the configuration manager halts the processing of data by the application and any related PLICs **60**.

[215] Next, the configuration manager **194** attempts to instantiate on the pipeline accelerator **14** (FIG. 1) a circuit, such as the circuit **220**, for generating the stream of values y of equation (1) in place of the failed data-processing application **190**.

[216] First, the configuration manager **194** determines whether the library **108** (FIGS. 4 and 9) includes a firmware file **180** (FIG. 9) that can instantiate such a circuit on a single PLIC **60**.

[217] If the library **108** (FIGS. 4 and 9) includes such a firmware file **180** (FIG. 9), then the configuration manager **194** downloads the file to a PLIC **60** of the pipeline accelerator **14** (FIG. 1), generates data-transfer objects **202** for transferring x and z to the PLIC and for transferring y from the PLIC, and starts the accelerator. Alternatively, the configuration manager **194** may omit some or all of the data-transfer objects **202** if the pipeline accelerator **14** receives x or z via the input port **24** or provides y via the output port **26**.

[218] If the exception manager **192** detects no failure of the single PLIC **60** after the start of the pipeline accelerator **14** (FIG. 1), then the configuration manager **194** allows the PLIC **60** and any related

data-processing application **190** (e.g., to provide x or z to receive y from the PLIC **60**) to continue processing data.

[219] But if the library **108** (FIGS. 4 and 9) includes no such firmware file **180** (FIG. 9), then the configuration manager **194** determines whether
5 the library **106** (FIGS. 4 and 8) includes a circuit-definition file **170** (FIG. 8) that describes a circuit, such as the circuit **220**, for generating y of equation (1).

[220] If the library **108** (FIGS. 4 and 9) includes such a circuit-definition file **170**, then the configuration manager **194** downloads the
10 corresponding firmware files **180** (FIG. 9) to the corresponding PLICs **60** of the pipeline accelerator **14** (FIG. 1). For example, if the file circuit-definition **170** describes the circuit **220** of FIG. 11, then the configuration manager **194** downloads the firmware files **180₁ – 180₇** into the respective PLICs **60₁ – 60₈** (the file **180₅** is downloaded into both the PLICs **60₅** and **60₆** as
15 discussed above in conjunction with Example 1). If however, the library **108** lacks at least one of the firmware files **180** corresponding to the circuit-definition file **170**, then the configuration manager **194** may, as discussed above in conjunction with Example 5, generate the omitted firmware file from templates in the library **102** (FIGS. 4 and 6), store the
20 generated firmware file in the library **108**, and download the stored firmware file into the respective PLIC **60**.

[221] But if the library **106** (FIGS. 4 and 8) includes no such circuit-definition file **170** (FIG. 8), then the configuration manager **194** may use the circuit-design tool (not shown) described in previously incorporated
25 U.S. Patent Application Ser. No. ____ (Attorney Docket No. 1934-023-03) to generate such a circuit-definition file as discussed above in conjunction with Example 5. Next, the configuration manager **194** generates (if necessary) and downloads the corresponding firmware files **180₁ – 180₇** into the corresponding PLICs **60₁ – 60₈** as described in the preceding paragraph.

[222] After downloading the firmware files **180₁ – 180₇** into the PLICs **60₁ – 60₈**, the configuration manager **194** instantiates the data-transfer objects **202₁ – 202₂₁** (**FIG. 12**) as discussed above in conjunction with Example 1, and starts the PLICs **60₁ – 60₈** and any related data-processing applications **190**.

[223] But if the configuration manager **194** cannot instantiate on the pipeline accelerator **14** (**FIG. 1**) a circuit for generating y of equation (1), then the configuration manager generates an error message in response to which an operator (not shown) can take corrective action. The configuration manager **194** may be unable to instantiate such a circuit because, e.g., the accelerator **14** lacks sufficient resources or does not support a compatible platform, or the library **102** (**FIGS. 4 and 6**) lacks the proper templates.

[224] Still referring to **FIGS. 3 and 10 – 11**, alternate embodiments of Example 8 are contemplated. For example, the configuration manager **194** may omit any number of the above-described steps, and perform the unomitted steps in any order. Furthermore, the exception manager **190** may be omitted, and the configuration manager **194** may directly detect the failure of the data-processing application **190** that generates y of equation (1), and may directly detect the failure of any other portion of the peer-vector machine **10** (**FIG. 1**).

System Save, Restore, and Redundancy

[225] **FIG. 15** is a block diagram of the peer-vector machine **10**, which, in addition to the host processor **12** and pipeline accelerator **14**, includes at least one redundant processing unit **250** and at least one redundant pipeline unit **252** according to an embodiment of the invention.

[226] The redundant processing units **250** and the redundant pipeline units **252** provide fault-tolerant capabilities in addition to the dynamic-reconfiguration capabilities described above in conjunction with

Examples 7 and 8. For example, if a PLIC **60** (**FIG. 3**) in the pipeline accelerator **14** fails, then the configuration manager **194** (**FIG. 10**) may dynamically reconfigure a redundant PLIC (not shown) on a redundant pipeline unit **252** to replace the failed PLIC **60** in a manner that is similar to that described above in conjunction with Example 7. Similarly, if the processing unit **32** (**FIG. 10**) of the host processor **12** fails, then the configuration manager **194** may dynamically reconfigure a redundant processing unit **250** to replace the failed processing unit in a manner that is similar to that described above in conjunction with Example 8. In addition, the configuration manager **194** may dynamically reconfigure a redundant processing unit **250** to replace a failed portion of the pipeline accelerator **14**, or may dynamically reconfigure one or more redundant PLICs on one or more of the redundant pipeline units **252** to replace a failed processing unit **32** or another failed portion of the host processor **12** in a manner that is similar to that described above in conjunction with Examples 7 and 8.

[227] Referring to **FIGS. 10-15** and Examples 7 and 8, the dynamic reconfiguration of the host processor **12** and the pipeline accelerator **14** may destroy the states of the, e.g., registers (not shown), in the host processor and in the pipeline accelerator. Consequently, once restarted after dynamic reconfiguration, the host processor **12** and pipeline accelerator **14** may need to reprocess all of the data processed prior to the failure that initiated the reconfiguration.

[228] Unfortunately, the reprocessing of pre-failure data may adversely affect some applications of the peer-vector machine **10**, such as the processing of data from a sonar array or other application where the peer-vector machine processes data in real time.

[229] **FIG. 16** is a block diagram of the peer-vector machine **10**, which includes system-restore capabilities according to an embodiment of the invention. Generally, this embodiment of the machine **10** periodically saves the states of some or all of the, e.g., registers, within the host

processor **12** and the pipeline accelerator **14**. Therefore, in the event of a failure and a subsequent restart, the peer-vector machine **10** can respectively restore the last-saved states to the host processor **12** and to the pipeline accelerator **14** so as to reduce or eliminate the volume of pre-failure data that the machine must reprocess.

[230] In addition to the host processor **12**, the pipeline accelerator **14**, the pipeline bus **20**, the optional router **31**, the optional redundant processing unit(s) **250**, and the optional redundant pipeline unit(s) **254**, this embodiment of the peer-vector machine **10** includes a system-restore server **260** and a system-restore bus **262**.

[231] During operation of the peer-vector machine **10**, the registers and other data-storing components of the host processor **12** and the pipeline accelerator **14** (and the redundant processing unit(s) **250** and pipeline unit(s) **252** if present and in use) periodically "dump" their contents onto the system-restore server **260** via the system-restore bus **262**. The separation of the system-restore bus **262** from the pipeline bus **20** reduces or eliminates a data-processing-speed penalty that this data dump may cause, and otherwise prevents a "bottleneck" on the bus **20**.

[232] After a dynamic reconfiguration but before a restart of the peer-vector machine **10**, the host processor **12** causes the server **260** to upload the last-saved set of data into the respective registers and other data-storing components.

[233] Therefore, after the restart, the peer-vector machine **10** starts processing data from the point in time of the last-dumped set of data, and thus reprocesses only the pre-failure data that it processed between the last data dump and the failure.

[234] Consequently, by reducing the amount of pre-failure data that the peer-vector machine **10** reprocesses, the system-restore server **260** and the system-restore bus **262** provide a reduction in the overall

data-processing time whenever the configuration manager **194** dynamically reconfigures and restarts the peer-vector machine.

[235] Still referring to **FIG. 16**, other embodiments of the peer-vector machine **10** are contemplated. For example, the system-restore bus **262**
5 may be omitted, and the host processor **12** and the pipeline accelerator **14** (and the redundant processing unit(s) **250** and the redundant pipeline units **252** if present and in use) dump data to the system-restore server **260** via the pipeline bus **20**.

[236] **FIG. 17** is a block diagram of a hardwired pipeline **44** that
10 includes a save/restore circuit **270** according to an embodiment of the invention. The circuit **270** allows the pipeline **44** to periodically "dump" the data within the pipeline's working registers (not shown in **FIG. 17**), and to restore the dumped data, as discussed above in conjunction with **FIGS. 15-16**.

[237] The save/restore circuit **270** is part of the framework-services layer **72** (**FIGS. 2-3**), and causes the working registers (not shown in **FIG. 17**) of the hardwired pipeline **44** to dump their data to the system-restore server **260** (**FIG. 16**) via the system-restore bus **262** under the control of a data-save manager **272**, which is executed by the processing unit **32** of the
20 host processor **12** (**FIG. 10**). The data-save manager **272** and the circuit **270** may communicate with one another by sending messages over the system-restore bus **262**, or over the pipeline bus **20** (**FIG. 16**).
Furthermore, the data-save manager **272** may be a part of the configuration manager **194** (**FIG. 10**), or the configuration manager **194** may perform the
25 function(s) of the data-save manager.

[238] During a system restore, the save/restore circuit **270** causes the working registers (not shown in **FIG. 17**) of the hardwired pipeline **44** to load saved data (typically the lasted-saved data) from the system-restore server **260** (**FIG. 16**) via the system-restore bus **262** under the control of a
30 data-restore manager **274**, which is executed by the processing unit **32** of

the host processor **12** (**FIG. 10**). The data-restore manager **274** and the circuit **270** may communicate with one another by sending messages over the system-restore bus **262**, or over the pipeline bus **20** (**FIG. 16**).

Furthermore, the data-restore manager **274** may be a part of the
5 configuration manager **194** (**FIG. 10**), or the configuration manager **194** may perform the function(s) of the data-restore manager.

[239] In addition to the save/restore circuit **270**, the hardwired pipeline **44** includes one or more configurable registers and logic **276**, and one or more exception registers and logic **278**. The configurable registers
10 and logic **276** receive and store configuration data from the configuration manager **88** (see also **FIG. 3**), and use this stored configuration data to configure the pipeline **44** as previously described. The exception registers and logic **274** generate and store exception data in response to exceptions that occur during operation of the pipeline **44**, and provide this data to the
15 exception manager **86** (see also **FIG. 3**) for handling as previously described.

[240] Still referring to **FIG. 17**, the operation of the hardwired pipeline **44** is described according to an embodiment of the invention.

[241] During normal operation, the data-save manager **272**
20 periodically causes the save/restore circuit **270** to dump the data from selected working registers (not shown in **FIG. 17**) within the hardwired pipeline **44** to the system-restore server **260** via the system-restore bus **262**. Data within the configurable register(s) **276** typically selects which working registers dump their data, and the data may so select any number
25 of the working registers. Alternatively, the data-save manager **272** may cause the save/restore circuit **270** to dump data from the selected working registers via the pipeline bus **20**. Furthermore, if a data dump from one or more of the selected working registers fails, then the exception register(s) and logic **278** may send a corresponding exception to the exception
30 manager **86**. In response to such an exception, the configuration manager

194 may repeat the data-dump operation, at least for the hardwired pipeline(s) **44** that generate the exception.

[242] During a system-restore operation, the data-restore manager **274** causes the save/restore circuit **270** to load previously dumped and saved data from the system-restore server **260** (**FIG. 16**) into the respective working registers (not shown in **FIG. 17**) within the hardwired pipeline **44** via the system-restore bus **262** or the pipeline bus **20**. Before loading the data, the configuration manager **194** (**FIG. 10**) typically loads the configurable register(s) **276** with data that selects which working registers are to load data. Alternatively, data identifying the working registers which are to load restored data may have been previously stored in nonvolatile memory within the configuration register(s) and logic **276**. The save/restore circuit **270** may then run a check to make sure that it properly loaded the restore data. If the check fails, then the exception register(s) and logic **278** may send a corresponding exception to the exception manager **86**. In response to such an exception, the configuration manager **194** may repeat the system-restore operation, at least for the hardwired pipeline(s) **44** that generate the exception.

[243] **FIG. 18** is a more-detailed block diagram of the hardwired pipeline **44** of **FIG. 17** according to an embodiment of the invention.

[244] In addition to the save-restore circuit **270**, the hardwired pipeline **44** includes one or more working registers **280** (for clarity, only one working register is shown in **FIG. 18**), a respective input-data multiplexer **282** for each working register, a load port **281**, a data-input port **283**, and a data-output port **285**.

[245] The save-restore circuit **270** includes a respective data-save register **284** and a respective data-restore register **286** for each working register **280**, saved-data transmit logic **288**, and restored-data receive logic **290**.

[246] Still referring to **FIG. 18**, the operation of the hardwired pipeline **44** is described according to an embodiment of the invention.

[247] During normal operation, the data-save manager **272** causes the data-save register **284** to download the data from the corresponding
5 working register **280** during each predetermined number of cycles of the save-restore clock. The data-save manager **272** also causes the transmit logic **288** to transfer the data from the register **284** to the system-restore server **260** (**FIG. 16**), typically at the same rate at which the register **284** downloads data from the working register **280**. Furthermore, the working
10 register **280** may load data from the data-input port **283** via the multiplexer **282** in response to a hardwired-pipeline clock and a load command on the load port **281**, and may provide data via the data-output port **285**.
Alternatively, the save-restore circuit **270** may include fewer data-save registers **284** than working registers **280**, such that a single data-save
15 register may serve multiple working registers, perhaps even all of the working registers within the pipeline **44**. In such an alternative embodiment, such a data-save register **284** cooperates with the transmit logic **288** to download data from the corresponding working registers **280** in a serial fashion.

20 [248] During a system-restore operation, the data-restore manager **274** causes the receive logic **290** to load previously saved data from the system-restore server **260** (**FIG. 16**) and into the data-restore registers **286** during each predetermined number of cycles of the save-restore clock. The data-restore manager **274** also causes each data-restore register **286** to
25 load the previously saved data back into a respective working register **280** via a respective multiplexer **282**. Once all of the working registers **280** are loaded with respective previously saved data, then the configuration manager **194** may return the hardwired pipeline **44** to normal operation.
Alternatively, the save-restore circuit **270** may include fewer data-restore
30 registers **286** than working registers **280**, such that a single data-restore

register may serve multiple working registers, perhaps all of the working registers in the pipeline **44**. In such an alternative embodiment, such a data-restore register **286** cooperates with the receive logic **290** to upload data to the corresponding working registers **280** in a serial fashion.

5 **[249]** Referring to **FIGS. 1-18**, alternate embodiments of the peer vector machine **10** are contemplated. For example, some or all of the components of the peer vector machine **10**, such as the host processor **12** (**FIG. 1**) and the pipeline units **50** (**FIG. 3**) of the pipeline accelerator **14** (**FIG. 1**), may be disposed on a single integrated circuit.

10 **[250]** The preceding discussion is presented to enable a person skilled in the art to make and use the invention. Various modifications to the embodiments will be readily apparent to those skilled in the art, and the generic principles herein may be applied to other embodiments and applications without departing from the spirit and scope of the present
15 invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

WHAT IS CLAIMED IS:

1. A computing machine, comprising:
programmable integrated circuits;
5 a configuration registry operable to store a file that defines a circuit having portions; and
a processor coupled to the registry and, in response to the file, operable to instantiate a first one of the circuit portions on a first one of the programmable integrated circuits.
- 10 2. The computing machine of claim 1 wherein each of the programmable integrated circuits comprises a respective field-programmable gate array.
3. The computing machine of claim 1 wherein each of the circuit portions comprises a respective hardwired pipeline.
- 15 4. The computing machine of claim 1 wherein the processor is further operable to:
instantiate a second of the circuit portions on a second one of the programmable integrated circuits; and
generate and execute a data-transfer object that is operable to
20 receive data from the first instantiated circuit portion and to provide the data to the second instantiated circuit portion.
5. The computing machine of claim 1 wherein the processor is further operable to:
instantiate a second of the circuit portions on a second one of the
25 programmable integrated circuits; and
generate and execute a data-transfer object that is operable to receive data from the first integrated circuit and to provide the data to the second integrated circuit.
6. The computing machine of claim 1 wherein:
30 the registry is further operable to store a firmware file that corresponds to the first circuit portion; and

the processor is operable to instantiate the first circuit portion by providing the firmware file to the first integrated circuit.

7. The computing machine of claim 1 wherein:

the processor is operable to generate a firmware file that corresponds
5 to the first circuit portion; and

the processor is operable to instantiate the first circuit portion by providing the firmware file to the first integrated circuit.

8. The computing machine of claim 1 wherein:

the registry is further operable to store a firmware file that
10 corresponds to the first circuit portion;

the processor is further operable to generate a firmware file that corresponds to a second one of the circuit portions; and

the processor is further operable to instantiate the first and second circuit portions by providing the stored firmware file to the first integrated
15 circuit and by providing the generated firmware file to a second one of the integrated circuits.

9. The computing machine of claim 1 wherein:

the registry is further operable to store a firmware file that corresponds to a second one of the circuit portions;

20 the processor is further operable to generate a firmware file that corresponds to the first circuit portion; and

the processor is further operable to instantiate the first and second circuit portions by providing the stored firmware file to a second one of the integrated circuits and by providing the generated firmware file to the first
25 integrated circuit.

10. The computing machine of claim 1 wherein the processor is further operable to configure an operating parameter of the instantiated first circuit portion by sending configuration data to the first integrated circuit.

11. The computing machine of claim 1 wherein the processor is
30 further operable to:

determine whether the programmable integrated circuits are together operable to hold all of the circuit portions; and

if the programmable integrated circuits are together operable to hold all of the circuit portions, then instantiating each of the circuit portions on a
5 respective one of the integrated circuits.

12. The computing machine of claim 1 wherein the processor is further operable to:

determine whether the programmable integrated circuits are together operable to hold all of the circuit portions; and

10 if the programmable integrated circuits are not together operable to hold all of the circuit portions, then instantiating a second one of the circuit portions on the first integrated circuit.

13. The computing machine of claim 1 wherein:

each of the circuit portions is operable to perform a respective
15 function; and

the processor is further operable to,

determine whether the programmable integrated circuits are together operable to hold all of the circuit portions; and

if the programmable integrated circuits are not together
20 operable to hold all of the circuit portions, then executing the function of a second one of the circuit portions.

14. A computing machine, comprising:

a configuration registry operable to store a file that defines a circuit having one or more portions that are each operable to perform a respective
25 function; and

a processor coupled to the registry and, in response to the file, operable to,

determine whether a programmable integrated circuit is available to hold any of the circuit portions, and

if no programmable integrated circuit is available to hold any of the circuit portions, then executing the functions of the circuit portions.

15. A system, comprising:

5 a computing machine, comprising,

programmable integrated circuits,

a configuration registry operable to store a file that defines a circuit having portions, and

10 a processor coupled to the registry and, in response to the file, operable to instantiate a first one of the circuit portions on a first one of the programmable integrated circuits.

16. A system, comprising:

a computing machine, comprising,

15 a configuration registry operable to store a file that defines a circuit having one or more portions that are each operable to perform a respective function, and

a processor coupled to the registry and, in response to the file, operable to,

20 determine whether a programmable integrated circuit is available to hold any of the circuit portions, and

if no programmable integrated circuit is available to hold any of the circuit portions, then executing the functions of the circuit portions.

17. A method, comprising:

25 reading with a processor a file that defines a circuit having portions;

and

instantiating with the processor and, in response to the file a first one of the circuit portions on a first programmable integrated circuit.

18. The method of claim 17 wherein the first programmable
30 integrated circuit comprises a field-programmable gate array.

19. The method of claim 17, further comprising performing a pipelined operation with the instantiated first circuit portion.

20. The method of claim 17, further comprising:
instantiating with the processor a second circuit portion on a second
5 integrated circuit;

executing with the processor a data-transfer object that is operable to receive data from the first instantiated circuit portion and to provide the data to the second instantiated circuit portion.

21. The method of claim 17, further comprising:

10 instantiating with the processor a second circuit portion on a second integrated circuit;

executing with the processor a data-transfer object that is operable to receive data from the first integrated circuit and to provide the data to the second integrated circuit.

15 22. The method of claim 17 wherein the processor is operable to instantiate the first circuit portion by providing a corresponding firmware file to the first integrated circuit.

23. The method of claim 17, further comprising:

generating with the processor a firmware file that corresponds to the
20 first circuit portion; and

wherein the processor is operable to instantiate the first circuit portion by providing the firmware file to the first integrated circuit.

24. The method of claim 17, further comprising configuring an operating parameter of the instantiated first circuit portion by sending
25 configuration data to the first integrated circuit with the processor.

25. The method of claim 17, further comprising:

determining with the processor whether the first integrated circuit is operable to hold the first circuit portion and a second circuit portion; and

if the first integrated circuit is operable to hold the first and second
30 circuit portions, then instantiating with the processor the first and second circuit portions on the first integrated circuit.

26. The method of claim 17, further comprising:
determining with the processor whether a group of one or more
programmable integrated circuits that includes the first integrated circuit are
together operable to hold a group of one or more circuit portions that
5 includes the first circuit portion; and
if the group of programmable integrated circuits is not operable to
hold all of the one or more circuit portions, then executing with the
processor the function of a second one of the circuit portions.
27. A method, comprising:
10 determining with a processor whether a programmable integrated
circuit is available to hold any of one or more portions of a circuit, each
circuit portion operable to perform a respective function; and
if no programmable integrated circuit is available to hold any of the
one or more circuit portions, then executing with the processor the functions
15 of the one or more circuit portions.
28. A computing machine, comprising:
an electronic circuit operable to perform a function;
a first programmable integrated circuit; and
a first processor coupled to the electronic circuit and to the
20 programmable integrated circuit and operable to,
detect a failure of the electronic circuit, and
configure the programmable integrated circuit to perform the
function in response to detecting the failure.
29. The computing machine of claim 28 wherein the electronic
25 circuit comprises a hardwired pipeline.
30. The computing machine of claim 28 wherein the electronic
circuit is disposed on a second integrated circuit.
31. The computing machine of claim 28 wherein the electronic
circuit is disposed on a second programmable integrated circuit.
- 30 32. The computing machine of claim 28 wherein:

the electronic circuit is disposed on the first programmable integrated circuit; and

the processor is operable to configure the first programmable integrated circuit to perform the function by modifying the electronic circuit.

5 33. The computing machine of claim 28 wherein the electronic circuit comprises a second processor operable to execute instructions that cause the second processor to perform the function.

34. The computing machine of claim 28 wherein the first programmable circuit comprises a field-programmable gate array.

10 35. The computing machine of claim 28 wherein the processor is operable configure the first programmable integrated circuit to perform the function by instantiating the electronic circuit on the first programmable integrated circuit.

36. A system, comprising:
15 a computing machine, comprising,
 an electronic circuit operable to perform a function,
 a first programmable integrated circuit, and
 a first processor coupled to the electronic circuit and to the programmable integrated circuit and operable to,
20 detect a failure of the electronic circuit, and
 configure the programmable integrated circuit to perform the function in response to detecting the failure.

37. A computing machine, comprising:
 a hardwired pipeline operable to perform a function; and
25 a processor coupled to the pipeline and operable to,
 detect a failure of the pipeline, and
 perform the function in response to detecting the failure.

38. The computing machine of claim 37 wherein the hardwired pipeline is disposed on a programmable integrated circuit.

30 39. The computing machine of claim 37 wherein the hardwired pipeline is disposed on a field-programmable gate array.

40. The computing machine of claim 37 wherein the processor is operable to perform the function by executing a software object that causes the processor to perform the function.

41. A system, comprising:

5 a computing machine, comprising,
a hardwired pipeline operable to perform a function, and
a processor coupled to the pipeline and operable to,
detect a failure of the pipeline, and
perform the function in response to detecting the failure.

10 42. A computing machine, comprising:

a programmable integrated circuit; and
a processor coupled to the programmable integrated circuit and,
operable to perform a function, and
if the processor becomes unable to perform the function,
15 operable to,

instantiate on the programmable integrated circuit a
hardwired pipeline operable to perform the function, and
cause the hardwired pipeline to perform the function.

43. The computing machine of claim 42 wherein the programmable
20 integrated circuit comprises a field-programmable gate array.

44. A system, comprising:

a computing machine, comprising,
a programmable integrated circuit, and
a processor coupled to the programmable integrated circuit
25 and,

operable to perform a function, and

if the processor becomes unable to perform the function,
operable to,

30 instantiate on the programmable integrated circuit
a hardwired pipeline operable to perform the function,
and

cause the hardwired pipeline to perform the function.

45. A method, comprising:

detecting a failure of an electronic circuit to perform a predetermined function; and

5 configuring with a processor a programmable integrated circuit to perform the function in response to detecting the failure.

46. The method of claim 45 wherein configuring the programmable integrated circuit comprises instantiating the electronic circuit on the programmable integrated circuit.

10 47. The method of claim 45, further comprising:

wherein the electronic circuit is disposed on the programmable integrated circuit; and

configuring the programmable integrated circuit comprises modifying the electronic circuit.

15 48. A method, comprising:

detecting a failure of a hardwired pipeline to perform a function; and performing the function with a processor in response to detecting the failure.

49. The method of claim 48 wherein performing the function
20 comprises executing with the processor a software object that causes the processor to perform the function.

50. A method, comprising:

with a first processor, instantiating a hardwired pipeline on a programmable integrated circuit if a second processor fails to perform a
25 predetermined function; and

with the first processor, causing the hardwired pipeline to perform the function.

51. The method of claim 50 wherein the second processor comprises the first processor.

30 52. A computing machine, comprising:

a pipeline accelerator;

a host processor coupled to the pipeline accelerator; and
a redundant processor coupled to the host processor and to the
pipeline accelerator.

53. The computing machine of claim 52, further comprising:
5 wherein the pipeline accelerator comprises a pipeline unit; and
a redundant pipeline unit having a redundant programmable
integrated circuit and coupled to the pipeline accelerator, the host
processor, and the redundant processor.

54. An electronic system, comprising:
10 a computing machine, comprising,
a pipeline accelerator,
a host processor coupled to the pipeline accelerator, and
a redundant processor coupled to the host processor and to the
pipeline accelerator.

15 55. A computing machine, comprising:
a pipeline accelerator having a pipeline unit;
a host processor coupled to the pipeline accelerator; and
a redundant pipeline unit coupled to the pipeline accelerator and to
the host processor and including a redundant programmable integrated
20 circuit.

56. A system, comprising:
a computing machine, comprising,
a pipeline accelerator having a pipeline unit,
a host processor coupled to the pipeline accelerator, and
25 a redundant pipeline unit coupled to the pipeline accelerator
and to the host processor and including a redundant programmable
integrated circuit.

57. A computing machine, comprising:
a pipeline accelerator;
30 a host processor coupled to the pipeline accelerator; and

a recovery device coupled to the pipeline accelerator and to the host processor and operable to,

periodically save first data representing a state of the pipeline accelerator during a respective predetermined period, and

5 periodically save second data representing a state of the host processor during the respective predetermined period.

58. The computing machine of claim 57 wherein after a failure of the pipeline accelerator, the recovery device is further operable to restore to the pipeline accelerator the most recent first data.

10 59. The computing machine of claim 57 wherein after a failure of the pipeline accelerator, the recovery device is further operable to restore to the host processor the most recent second data.

60. The computing machine of claim 57 wherein after a failure of the host processor, the recovery device is further operable to restore to the
15 pipeline accelerator the most recent first data.

61. The computing machine of claim 57 wherein after a failure of the host processor, the recovery device is further operable to restore to the host processor the most recent second data.

62. The computing machine of claim 57, further comprising:
20 a pipeline bus;
wherein the host processor is coupled to the pipeline accelerator via the pipeline bus; and

wherein the recovery device is coupled to the pipeline accelerator and to the host processor via the pipeline bus.

25 63. The computing machine of claim 57, further comprising:
a pipeline bus;
a recovery bus that is separate from the pipeline bus;
wherein the host processor is coupled to the pipeline accelerator via the pipeline bus; and

30 wherein the recovery device is coupled to the pipeline accelerator and to the host processor via the recovery bus.

64. A system, comprising:
a computing machine, comprising,
a pipeline accelerator,
a host processor coupled to the pipeline accelerator, and
5 a recovery device coupled to the pipeline accelerator and to the
host processor and operable to,
periodically save first data representing a state of the
pipeline accelerator during a respective predetermined period,
and
10 periodically save second data representing a state of the
host processor during the respective predetermined period.
65. A method, comprising:
processing data with a pipeline accelerator and a host processor
coupled to the pipeline accelerator; and
15 processing the data with the pipeline accelerator and a redundant
processor coupled the pipeline accelerator if the host processor fails.
66. A method, comprising:
processing data with a pipeline unit of a pipeline accelerator and with
a host processor coupled to the pipeline accelerator; and
20 processing the data with the a redundant pipeline unit coupled to the
pipeline accelerator and to the host processor if the pipeline unit fails, the
redundant pipeline unit including a redundant programmable integrated
circuit.
67. A method, comprising:
25 periodically saving first data representing a state of a pipeline
accelerator during a respective predetermined period; and
periodically saving second data representing a state of a host
processor during the respective predetermined period, the host processor
being coupled to the pipeline accelerator.

68. The method of claim 67, further comprising restoring to the pipeline accelerator after a failure of the pipeline accelerator the most recent first data.

5 69. The method of claim 67, further comprising restoring to the host processor after a failure of the pipeline accelerator the most recent second data.

70. The method of claim 67, further comprising restoring to the pipeline accelerator after a failure of the host processor the most recent first data.

10 71. The method of claim 67, further comprising restoring to the host processor after a failure of the host processor the most recent second data.

72. The method of claim 67 wherein periodically saving the first and second data comprises periodically saving the first and second data via
15 a recovery bus that is separate from a bus over which the host processor and pipeline accelerator transfer processed data.

73. The method of claim 67 wherein periodically saving the first and second data comprises periodically saving the first and second data via a bus over which the host processor and pipeline accelerator transfer
20 processed data.

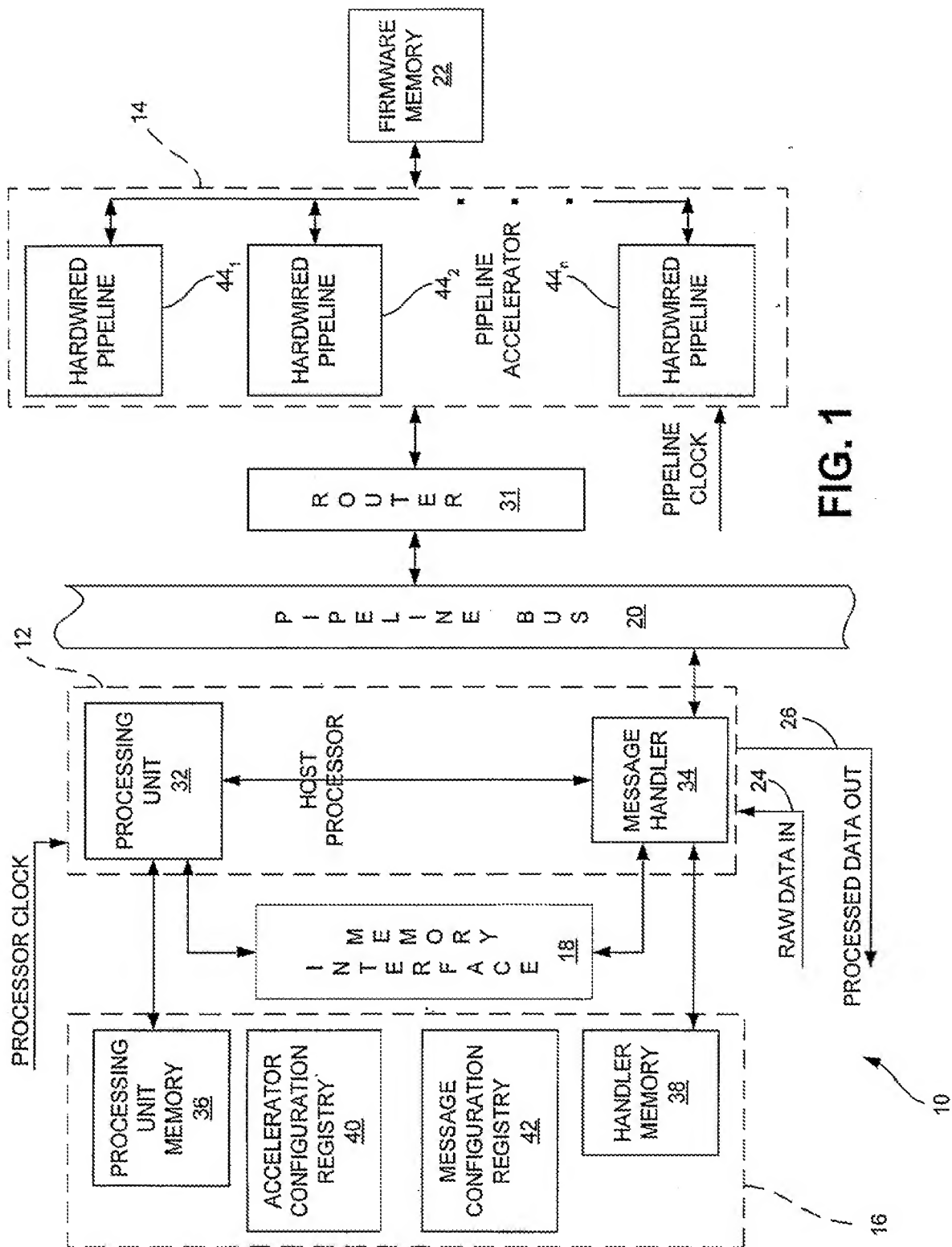


FIG. 1

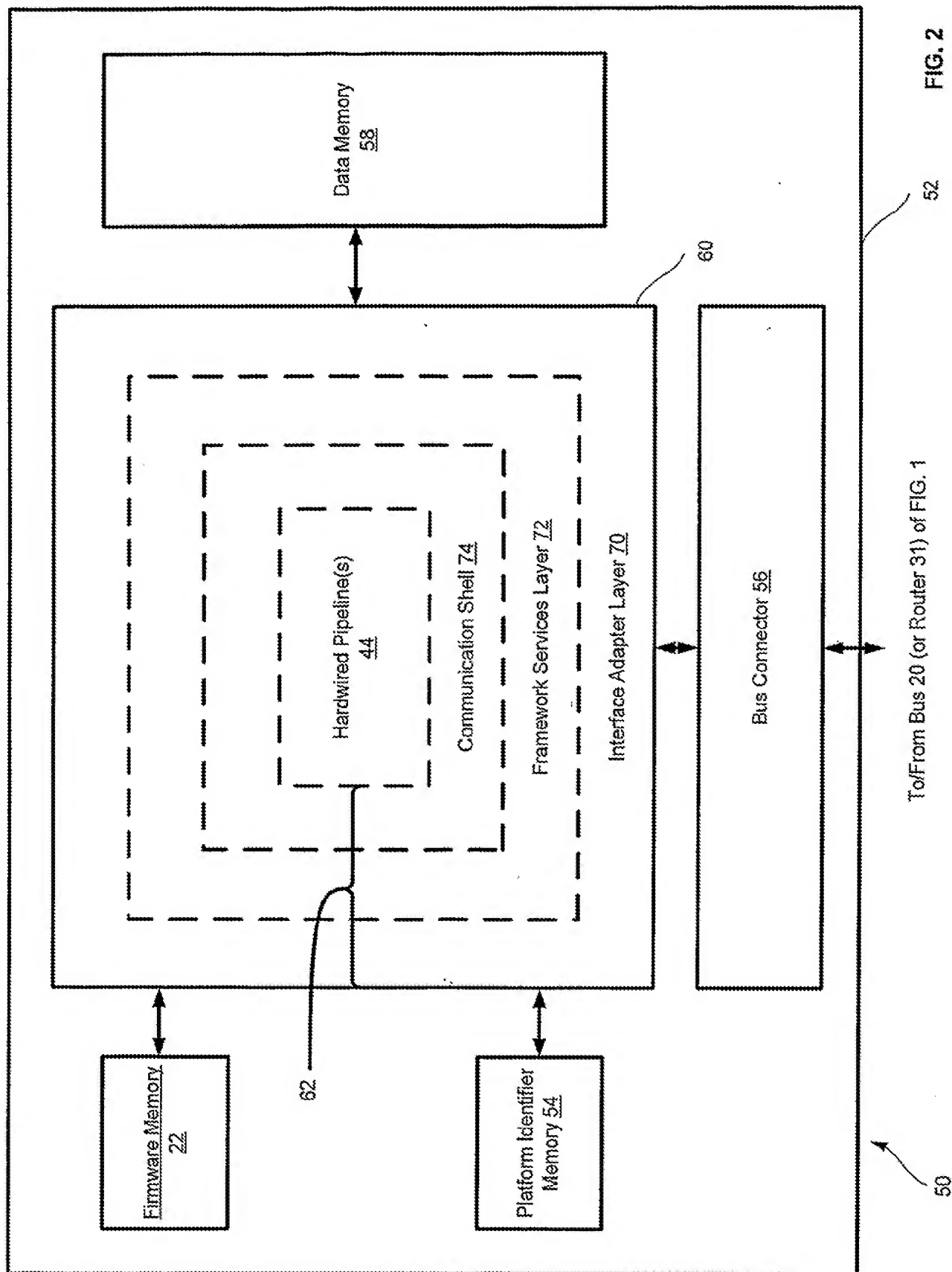
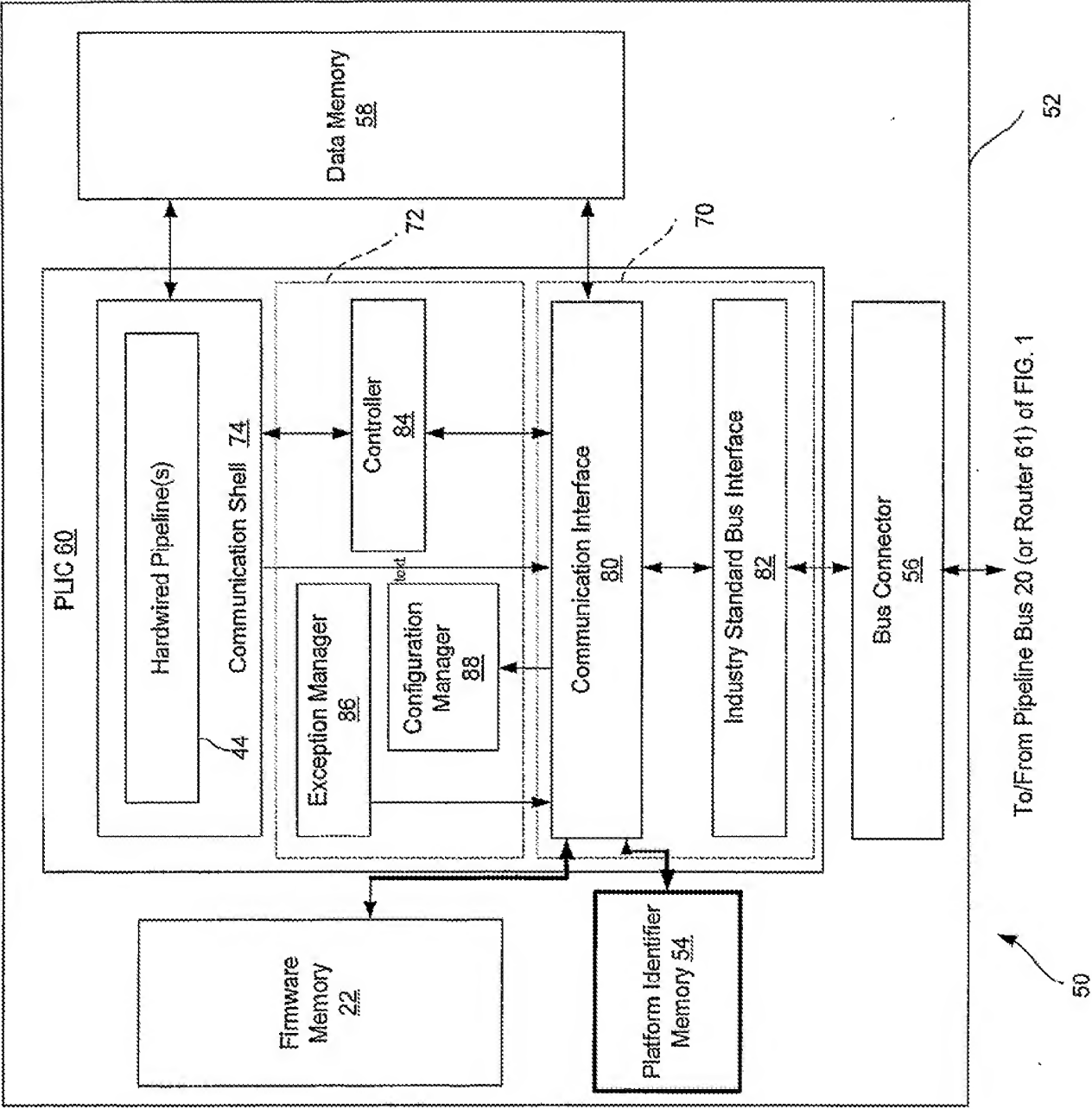


FIG. 2



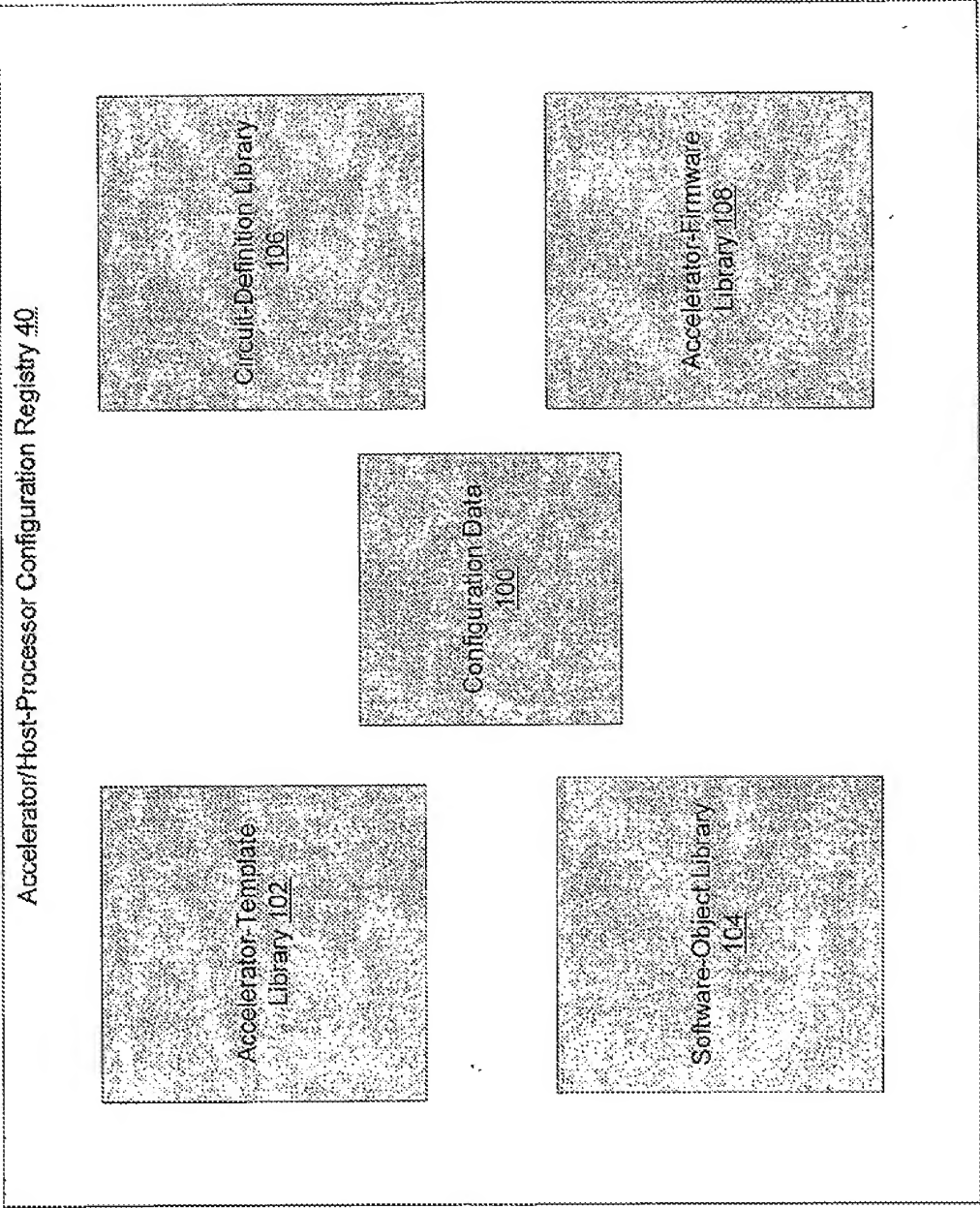
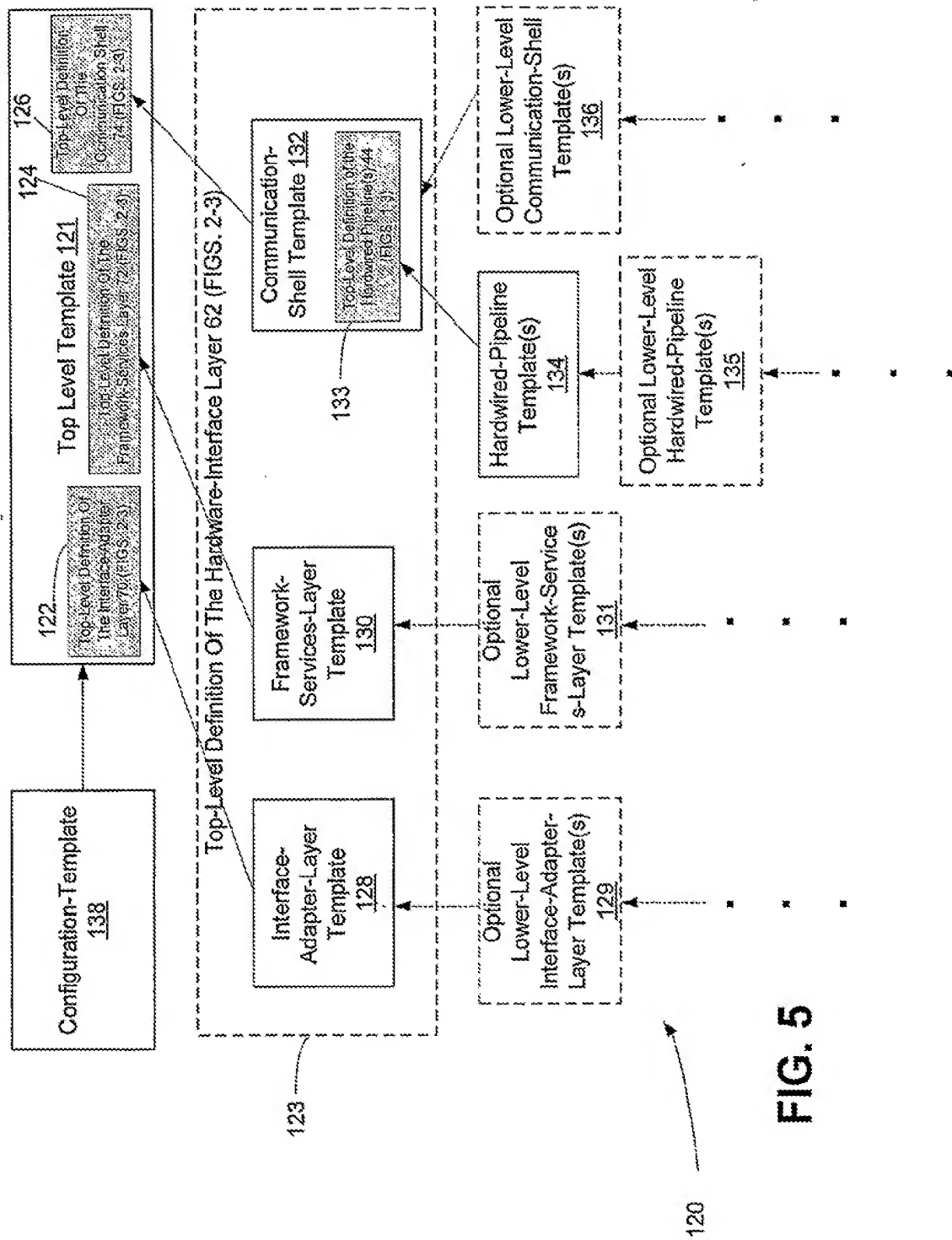


FIG. 4



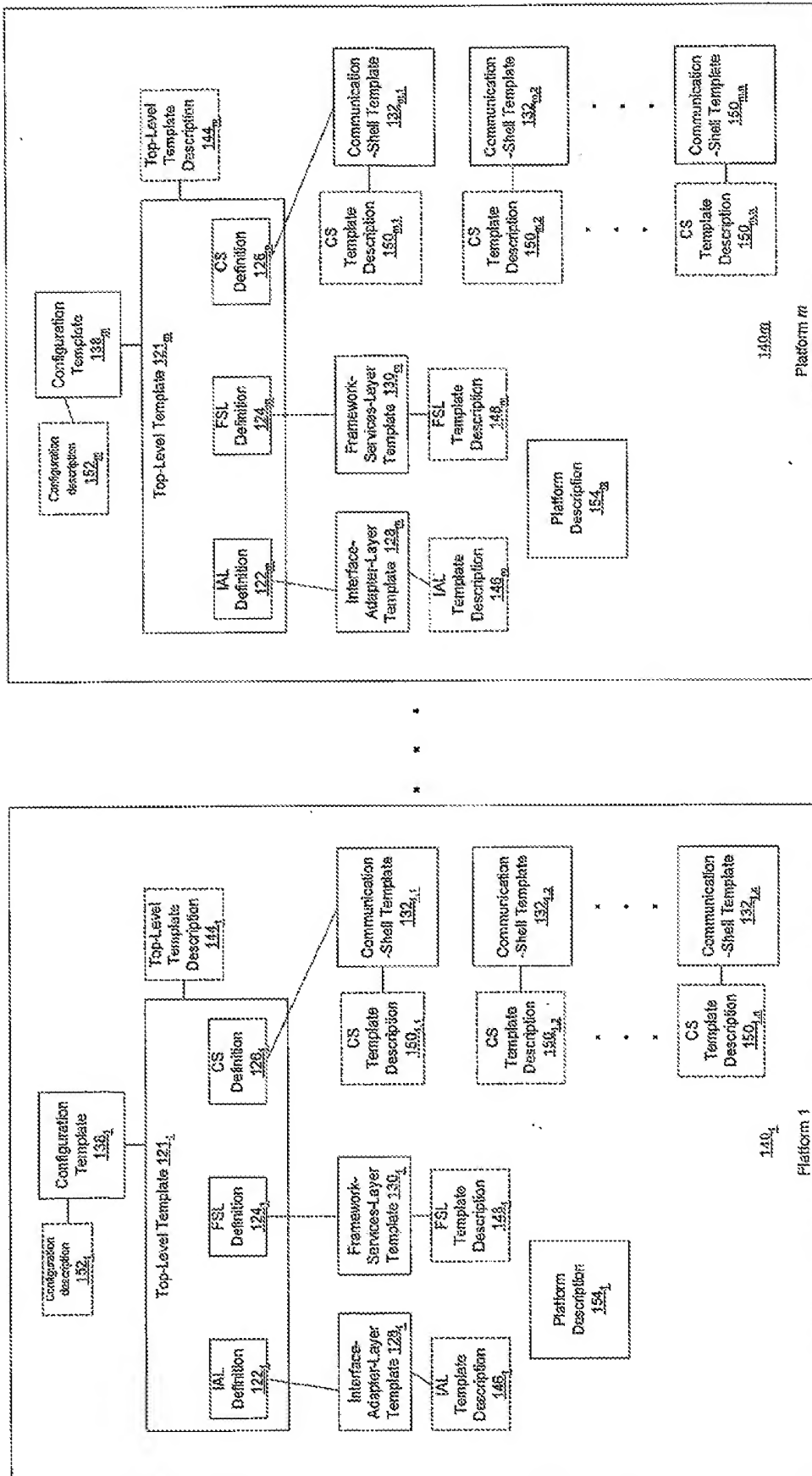
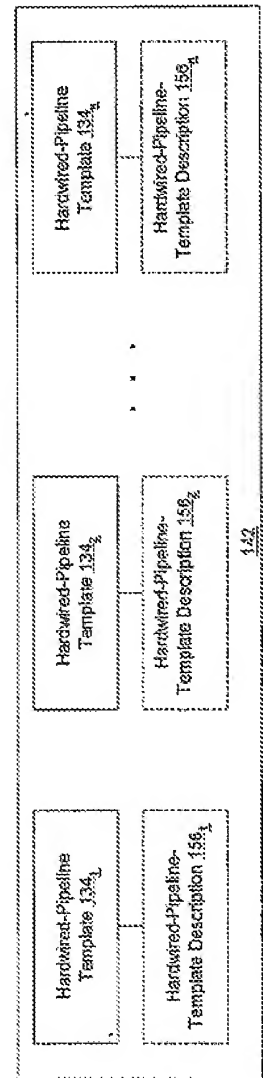


FIG. 6



102

FIG. 7

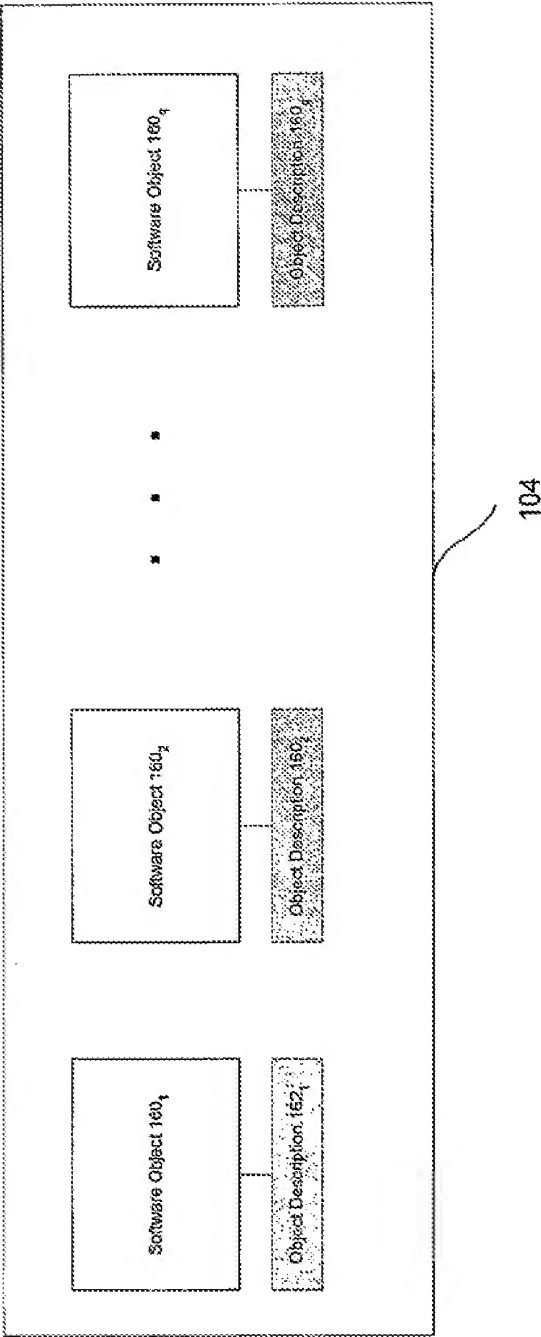


FIG. 8

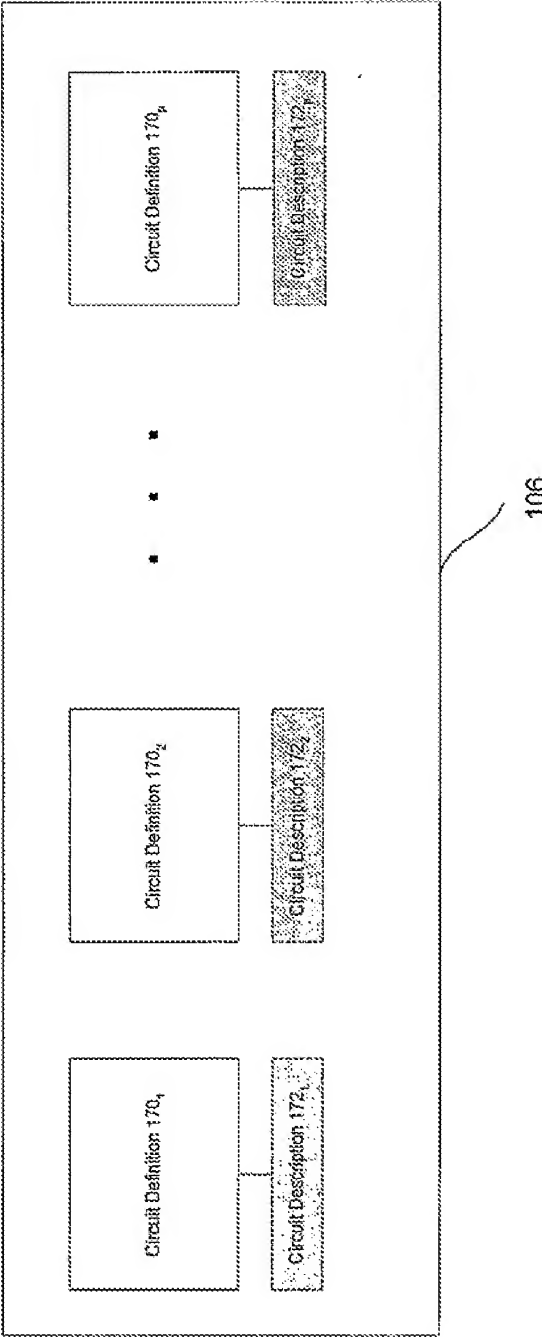
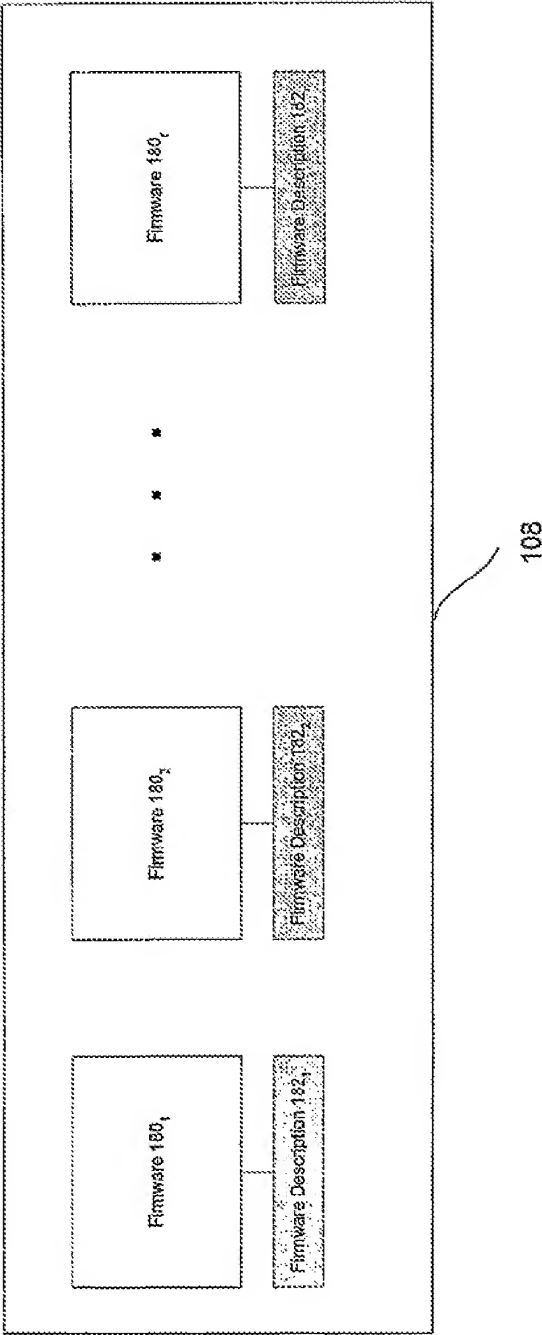


FIG. 9



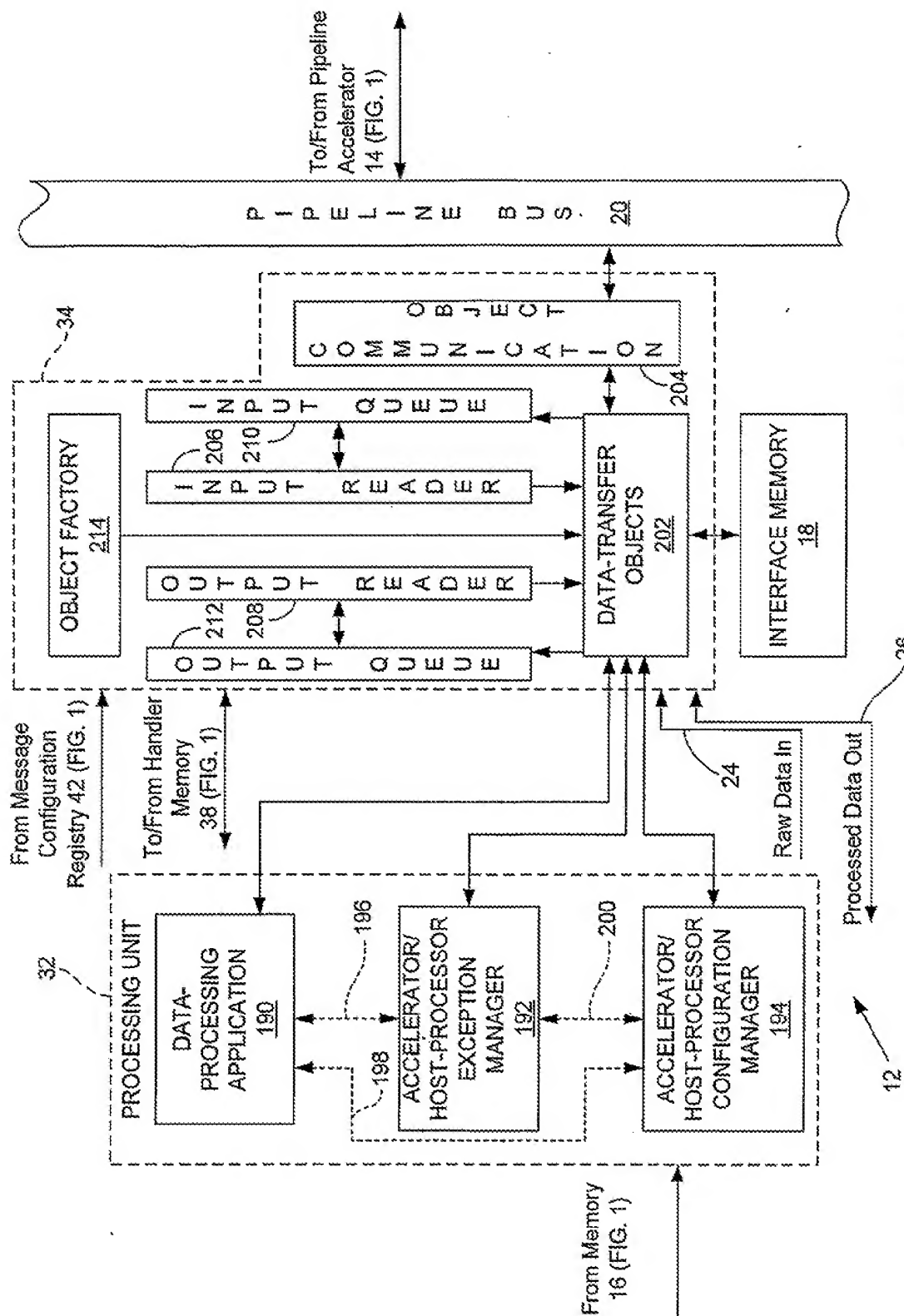


FIG. 10

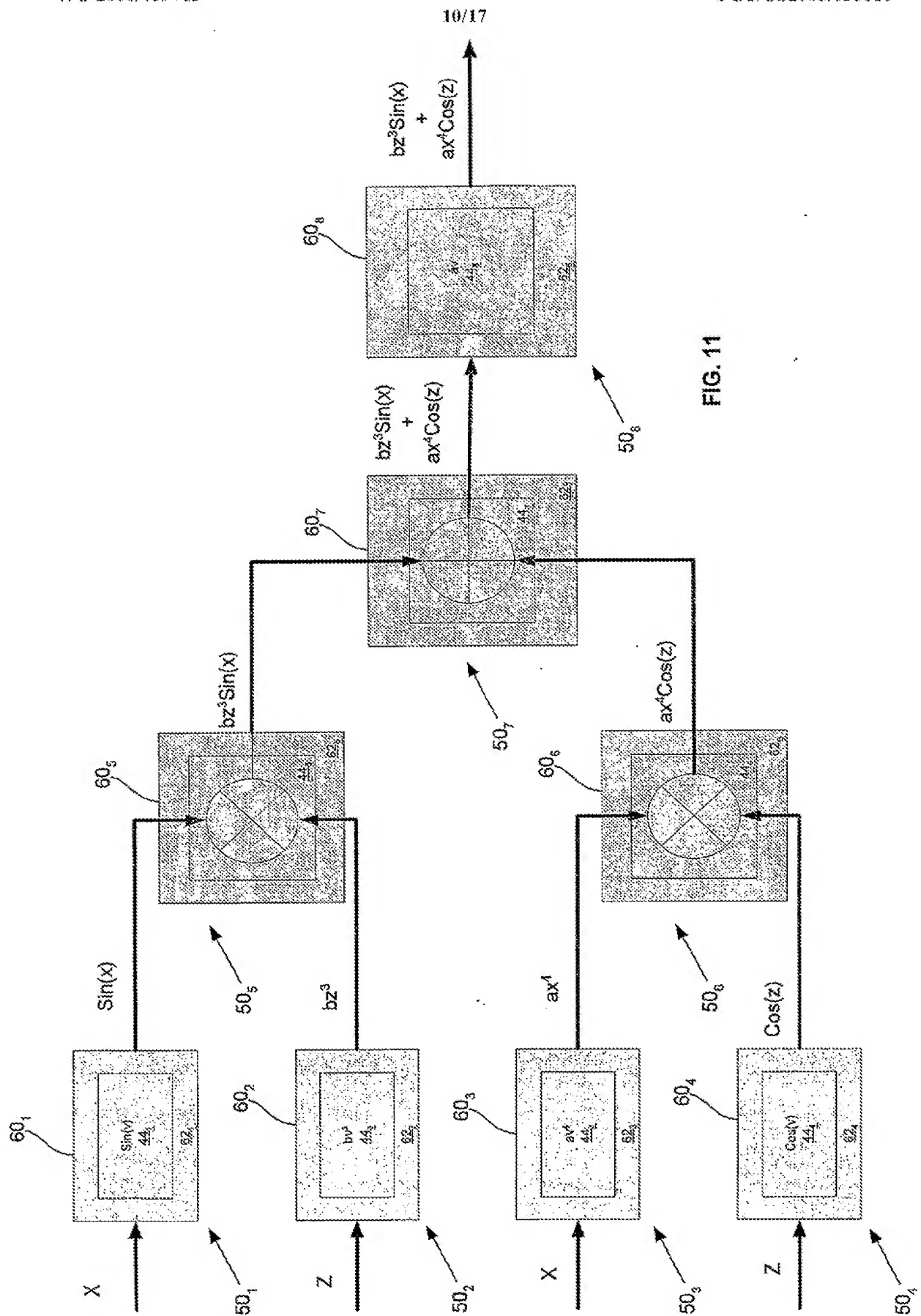
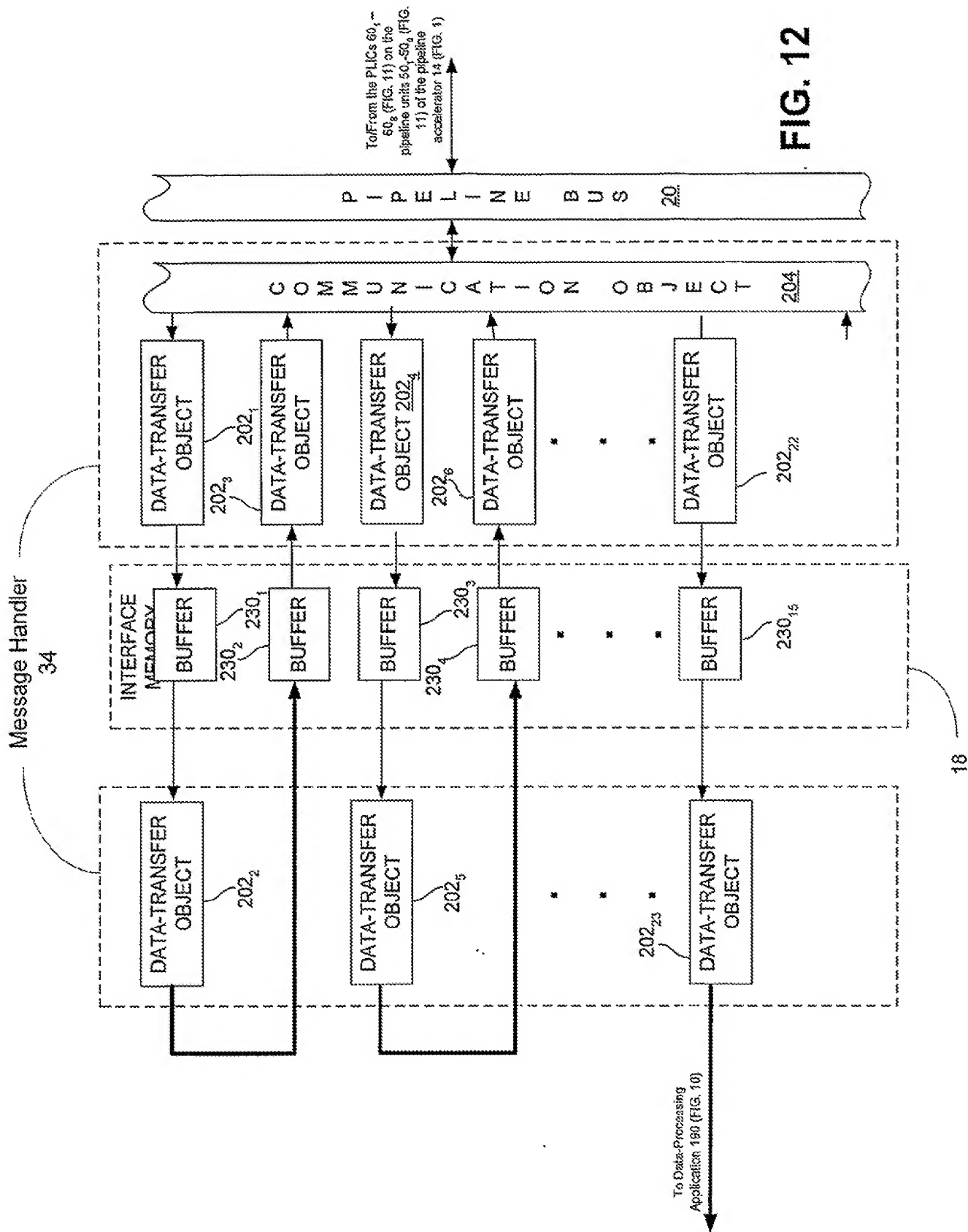


FIG. 11



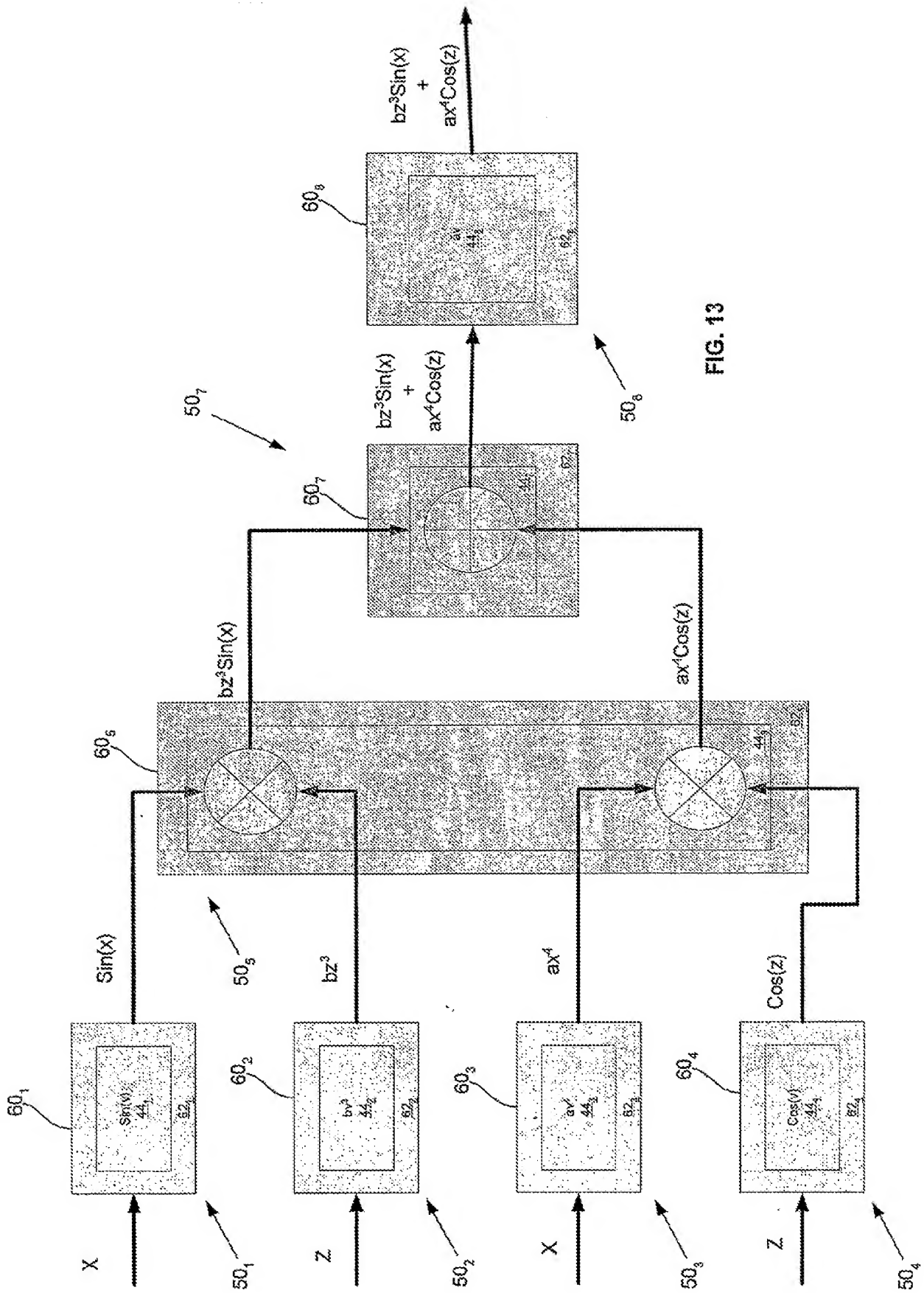
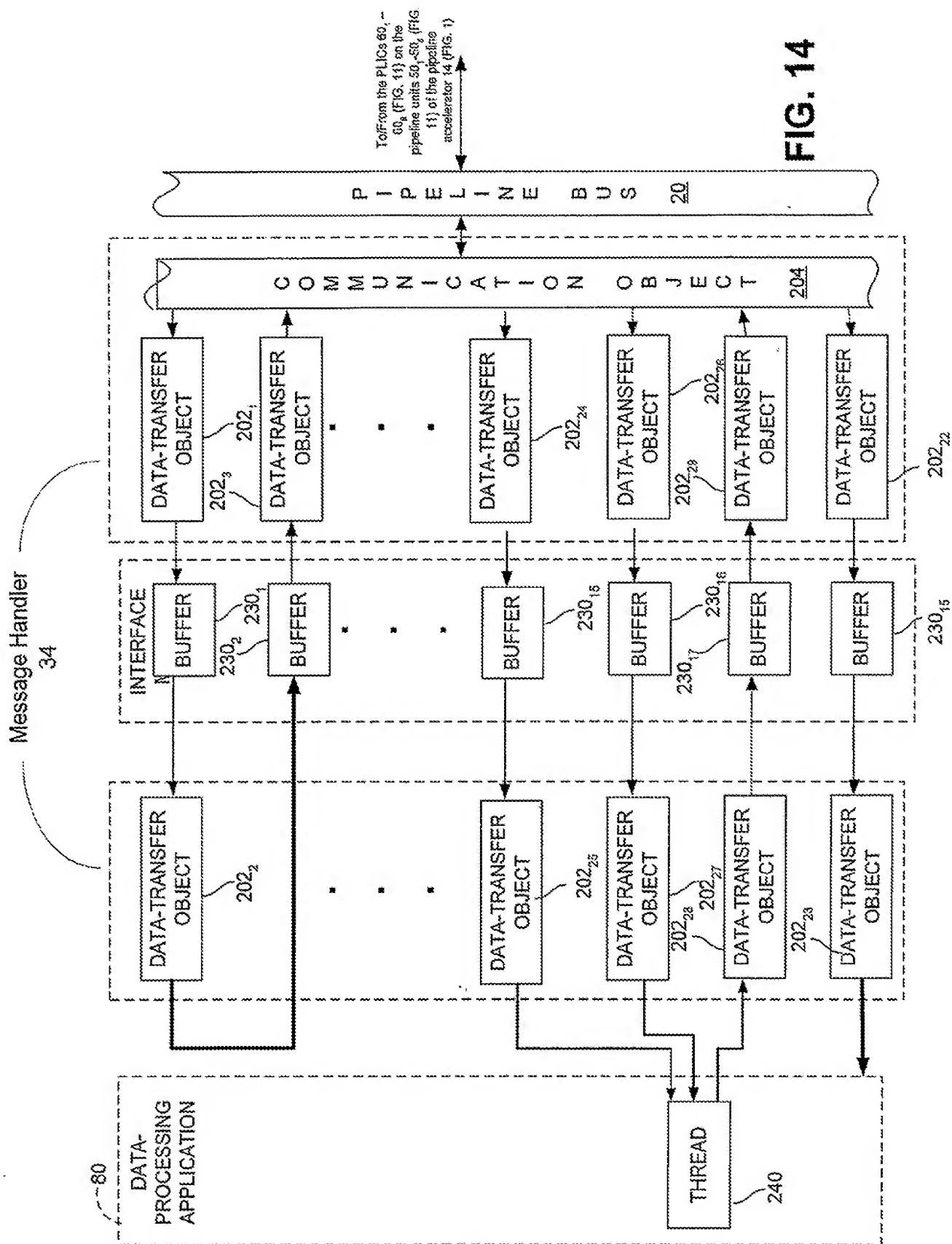
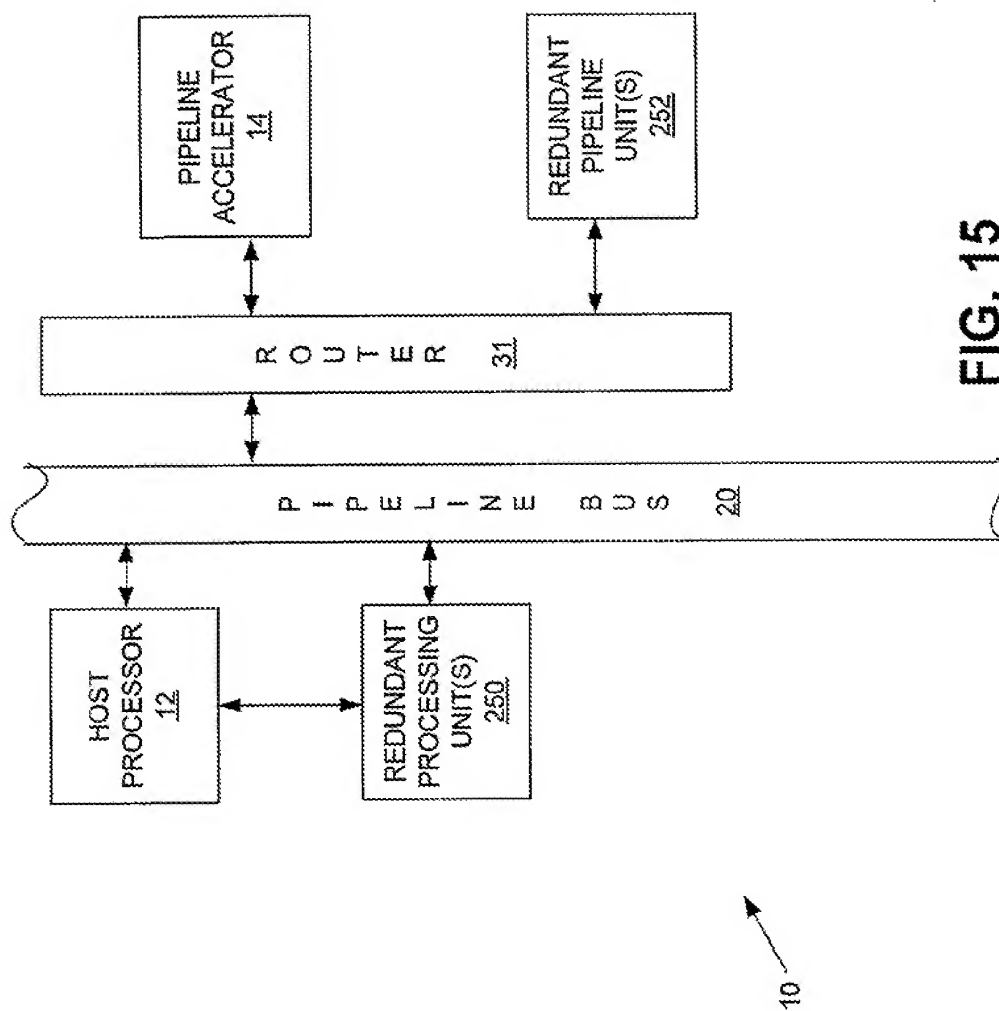


FIG. 13





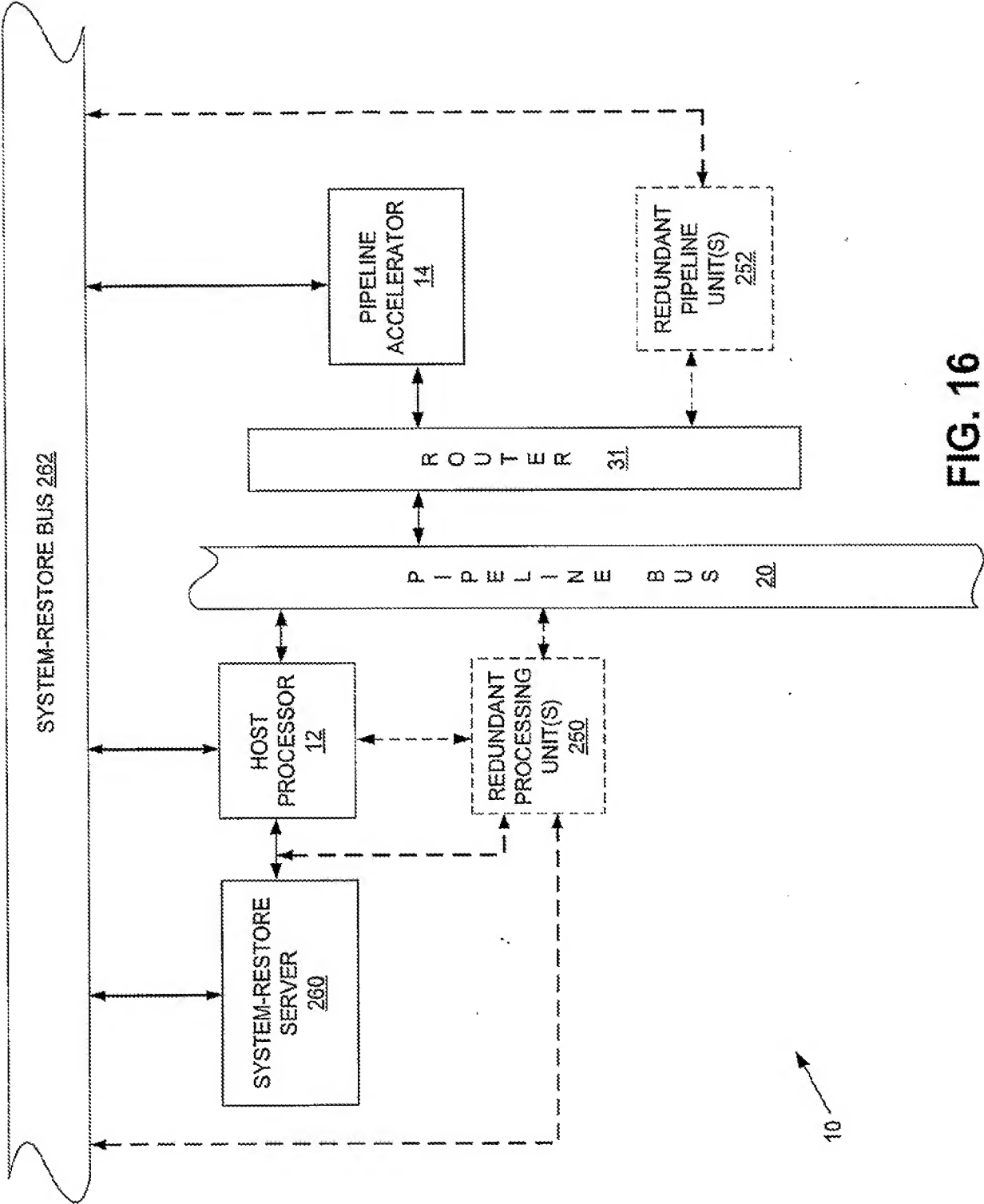
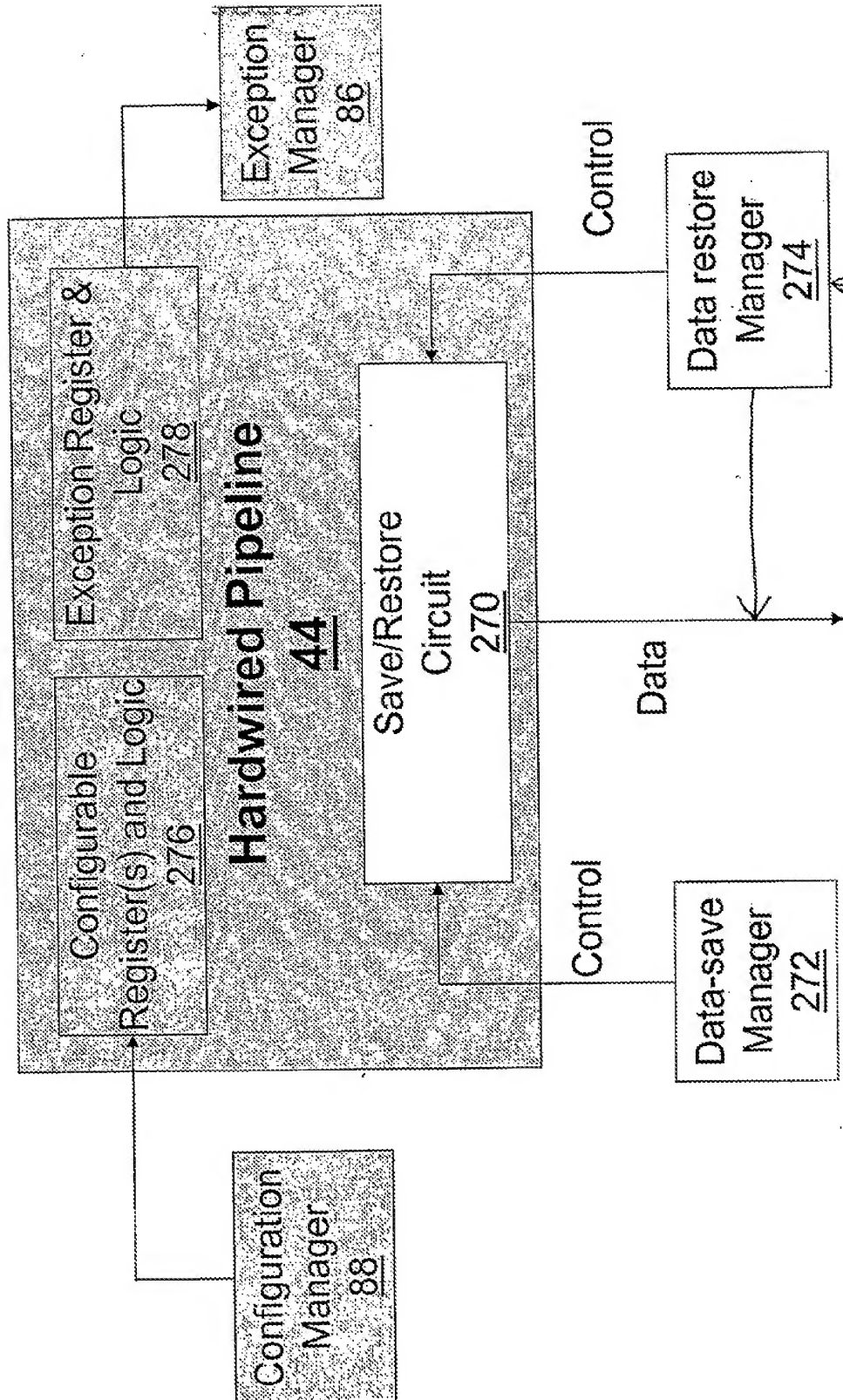


FIG. 16

FIG. 17



From
System Restore Bus 262 (FIG. 16)

FIG. 18

